

LETTER

FROM

THE SECRETARY OF THE TREASURY,

COMMUNICATING

A report of chemical analyses of sugars, molasses, &c., and of researches on hydrometers, made under the superintendence of Professor A. D. Bache by Professor R. S. McCulloh.

FEBRUARY 21, 1845.

Read, and ordered to be printed.

MARCH 3, 1845.

Ordered, that 500 additional copies be furnished for the use of the Senate.

TREASURY DEPARTMENT, *February 19, 1845.*

SIR: I have the honor to transmit, for the information of the Senate, a letter from Professor A. D. Bache, communicating a report of chemical analyses of sugars, molasses, etc., made under his superintendence, by Professor R. S. McCulloh, in obedience to a resolution of the House of Representatives passed 21st July, 1842; and of researches on hydrometers, in compliance with a request of this department, made in consequence of representations that the present system of ascertaining the strength of distilled spirits is inaccurate, and under the authority of an act of Congress approved 12th January, 1825.

I am, very respectfully, your obedient servant,

GEORGE M. BIBB,
Secretary of the Treasury.

Hon. WILLIE P. MANGUM,
President of the United States Senate.

Letter of Professor A. D. Bache, transmitting a report of inquiries and experiments, made under his superintendence, by Professor R. S. McCulloh, on sugars, hydrometers, &c.

OFFICE OF WEIGHTS AND MEASURES,

February 17, 1845.

SIR: On the 13th of March last, I was requested by the Treasury Department to undertake the experiments necessary for the comparison of hydrometers in reference to their use in the collection of the revenue. This request was stated in the letter, hereto annexed, of the Secretary of the Treasury, the Hon. J. C. Spencer, to have been made in consequence of

representations to the department that Dycas's hydrometer, for testing the proofs of distilled spirits and liquors, used in the custom-houses of the United States, was not as accurate as was desirable. The department, at the same time, put at my disposal one of Dycas's instruments, together with one by Tucker & Dwelle, of Boston, and one of Sikes's hydrometers. There were others, also, at the office of weights and measures.

By an act of Congress, approved on the 12th of January, 1825, "the Secretary of the Treasury" is "authorized, under the direction of the President of the United States, to adopt and substitute such hydrometer as he may deem best calculated to promote the public interest, in lieu of that now prescribed by law, for the purpose of ascertaining the proofs of liquors;" and the subject appears to have received attention from the department at different times, without, however, definitive action in regard to it.

In accepting the duty thus assigned by the department, I reserved to myself, on a review of the ground of inquiry and a consideration of the experiments to be made, with the time within which the department required their results, to ask for an assistant, to whom the inquiries and experiments might be committed, under my direction.

In June last, I was requested further to undertake the scientific investigations required by the act of Congress of the 3d of March, 1843, in relation to sugar and sirups, and to the saccharine matters contained in them, and to connect these with researches into the saccharine and extractive matters in various kinds of liquors. It was plain that the investigations thus required, together with the former ones, relating to hydrometers, could not be accomplished in any reasonable time, without putting aside the adjustment and comparisons of the weights and measures. I therefore proposed to the department to appoint an assistant, who might, under my direction, make the investigations and researches required; and, on the request being granted, nominated Professor Richard S. McCulloh, formerly professor of mathematics, natural philosophy, and chemistry, in Jefferson College, Pennsylvania, as assistant in these inquiries. By this arrangement, the department has had all the advantage of the attainments of Mr. McCulloh as a mathematician and chemist, the devotion of his time solely to these objects, by which they have been rapidly advanced, and of whatever benefit it originally proposed to itself in my direction of the work. In justice to myself, I ought here to remark, that no compensation was asked or received by me for the superintendence in question.

After the appointment of Professor McCulloh, the general course of proceeding in the inquiries was soon marked out, and the work commenced. We have since conferred together, and corresponded frequently about the details of the inquiries and researches, but the discussion of the various questions belongs to him alone. The able report of Professor McCulloh, which I have now the honor to submit to the department, shows that I did not overrate the advantages of his services. This is, however, to be considered a report in part only, several questions being still reserved for examination, and time not having yet served for the full investigation of others.

The report consists of two parts: the first, on the analysis of sugars, sirups, and molasses; and the second on hydrometers. In the first, the different methods of ascertaining the quantity of cane sugar present in a pure solution are given, the details of the methods by evaporation, by specific

gravity of the solution, by fermentation, and by the polarization of light, and the application of the two last methods to the analysis of mixtures of different kinds of sugars are discussed. A popular exposition of the method by the polarization of light is followed by a statement of the modes of research and results of Biot and Ventzke, and a description of the apparatus used by them. The methods and formulæ are then applied to examples of analysis, and the various steps in experiment and calculation are minutely given. Practical remarks follow, in regard to the different compositions of molasses; the error of estimating the value of molasses by specific gravity; the error of the mode heretofore used of estimating the amount of crystallizable sugar in a solution, and its bearing upon the question of drawback; the steps in the manufacture of sugar, especially in relation to those where improvements are most desirable, and the researches required for improvement; the vacuum and steam process, and the sources of its advantages; the alleged frauds upon the revenue in the importation of molasses; the necessity and value of researches on saccharine substances by the methods explained in the report.

In the second part of Professor McCulloh's report, the hydrometer is discussed. The mathematical and mechanical theory of the instrument is given and applied to its graduation, to explain the origin of the different scales in use, to the corrections required, and to the effect of injuries to metallic hydrometers by indentations. The advantages of the decimal scale for hydrometers are pointed out, the mode of adapting the decimal scale hydrometer to use for liquors of different specific gravities is explained. The different materials of which hydrometers may be made, the methods of manufacture, and the conditions necessary to secure accuracy, are discussed. The description of the principal hydrometers, with an examination of their advantages and defects, and of their theory, follows, and includes the principal hydrometers of France, England, Germany, Holland, Switzerland, and the United States. The decimal scale hydrometer is compared with others, and its advantages in point of simplicity are insisted upon. The remarks in regard to the graduation of hydrometers lead naturally to a discussion of the temperature of the maximum density of water, in reference to which a very full examination of the experiments of Despretz is given, and the method of least squares is applied to calculate the most probable value of the temperature in question from his researches. The results of experiments on the dilatation of mixtures of water and alcohol are collected and represented graphically, the subject of the proof of liquors is discussed, and the report closes with a comparison of different hydrometers.

From the data thus brought together, aided by the results of the experiments which they suggest, it will be easy to meet the practical questions in hydrometry, and to furnish to the Government the means of securing uniformity in the collection of the revenue, and to practical men generally accurate instruments, adapted to the wants of their different arts. I have not thought it necessary, or even desirable, to delay the presentation of this report for the sake of rendering it more complete, as the supplementary matter may be appropriately given in a further report.

Very respectfully, yours,

ALEXANDER D. BACHE.

HON. GEORGE M. BIBB,

Secretary of the Treasury of the United States.

Letter from the Hon. John C. Spencer, Secretary of the Treasury, to Professor A. D. Bache, in relation to experiments upon hydrometers.

TREASURY DEPARTMENT, *March 13, 1844.*

SIR: It is represented to the department, that Dycas's hydrometer for testing the proof of distilled spirits and liquors, directed to be used for this purpose by an act of Congress passed as early as the year 1790, and still continued in use at the respective custom-houses in the United States, does not probably exhibit as much accuracy in this respect as some more modern instruments used for the purpose mentioned. It is therefore deemed important to the interests of the revenue that a careful and thorough investigation of the subject should be had; and I wish you to undertake the matter, and to institute suitable experiments with different hydrometers, and furnish me with the results. The department has in its possession one of Dycas's instruments, together with one invented by Tucker & Dwelle, of Boston, and also Sikes's hydrometer, said to be used at the custom-houses in England, all of which will be furnished you. It is believed that there are some instruments of the kind in the weights and measures or coast survey office, procured for public purposes by the late Mr. Hassler.

To place you in possession of all the information on the subject in the possession of the department, I would add, that, by the act of Congress of the 12th of January, 1825, the Secretary of the Treasury, under the direction of the President, is authorized "to adopt and institute such hydrometer as he may deem best calculated to promote the public interest, in lieu of that now prescribed by law for ascertaining the proofs of liquors, &c." It appears, that shortly after the passage of this law various tests and examinations were made, with the different instruments then in use, both at Washington, by the late Doctor Staughton, and at the United States mint in Philadelphia, by Doctor Patterson, father of the present director of the mint. The examination at this place was made with Dycas's hydrometer, Gay Lussac's alcoholometer, and an instrument invented by Tucker & Dwelle, of Boston. Mr. Secretary Rush, in giving the result of this examination, states that the "two former were found to give the same result, or with scarcely a perceptible difference; and each indicated a higher degree of strength in the liquor than the latter." The report of director Patterson's observations was lost by the conflagration of the Treasury building, in the year 1833; but, as no other instrument was substituted in the place of Dycas's at that time, it is probable no change was deemed expedient.

As some of these instruments are stated to be too delicate for ordinary use, it is proper that regard should be paid to that fact in the case of any hydrometer you may recommend, and due allowance made for their falling into unskilful hands, which is likely to be the case at the custom-houses.

I am, very respectfully, your obedient servant,

J. C. SPENCER,
Secretary of the Treasury.

Professor A. D. BACHE,
Superintendent of Weights and Measures, Washington.

PLATE I.

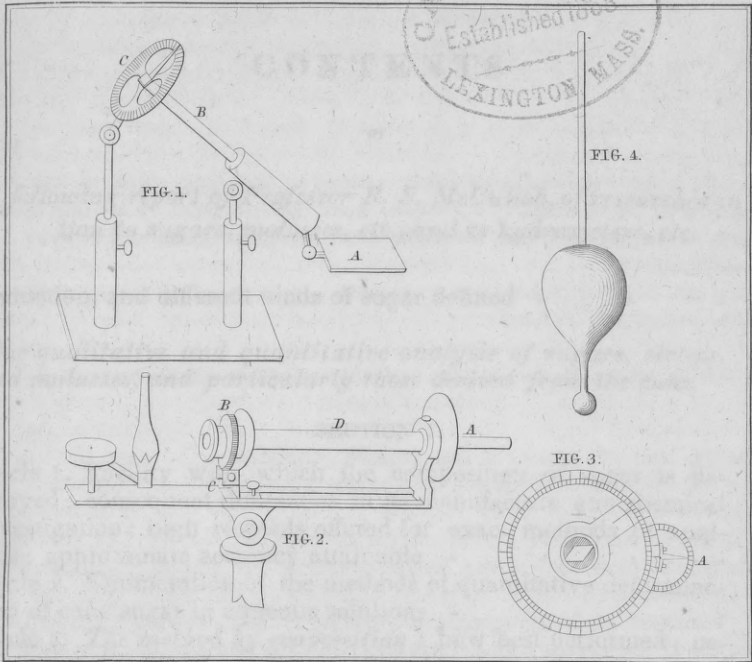
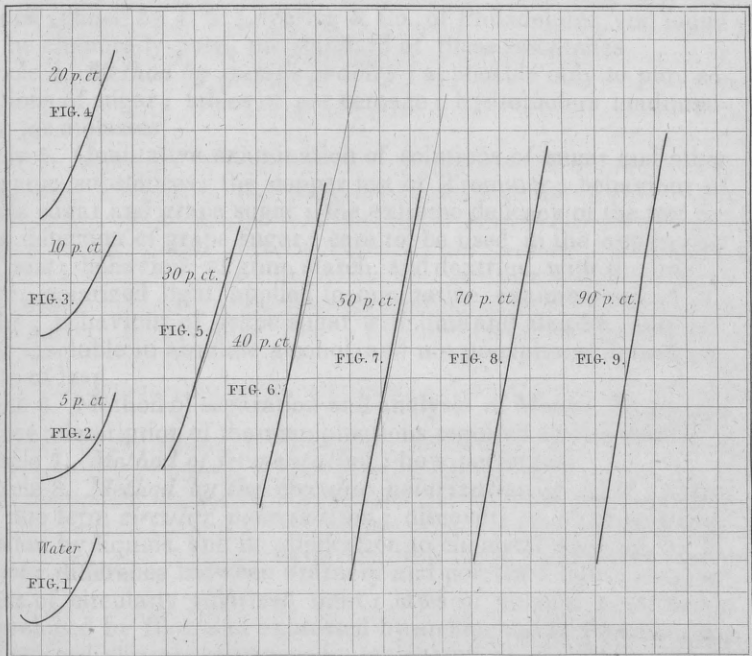


PLATE II.



THE UNITED STATES DEPARTMENT OF THE INTERIOR

J. C. SPENCER

Chief Clerk of the Treasury

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REPORT

TO

*Professor A. D. Buche, of researches made under his superintendence,
by Professor R. S. McCulloh, in relation to sugars, hydrometers, etc.*

WASHINGTON, February 18, 1845.

DEAR SIR : I have the honor to submit the following report of the progress I have made in the researches confided to me. You will, I trust, find that I have followed your instructions and advice; and the details herein set forth will be sufficient, together with such oral and informal written communications as I have from time to time made, to enable you to judge of the manner in which I have performed my task.

As the following report is intended for yourself as well as for general information, I have felt at liberty to go more into detail and to render it more scientific than I should otherwise have done. Since, however, the purely scientific parts will be of little interest to many, I have designated by a star, in the table of contents, such articles as would possibly be found most interesting to those who desire rather to know simply the results obtained.

Considerable time, of necessity, elapsed before I could procure the requisite apparatus: this enabled me more thoroughly to discuss the various memoirs contained in scientific journals and transactions; and you will, I hope, find that the time thus employed was not unprofitably spent.

I cannot refrain from expressing to you my grateful sense of the facilities I derived from my friend Professor Robert M. Patterson, director of the United States mint, through whose kindness I obtained books from the valuable library of the American Philosophical Society, and from whom I also received not only valuable information, but many suggestions which I found of service to me. I would also acknowledge the important services of Messrs. Booth and Boyé, in whose well-furnished laboratory I performed my chemical investigations, who frequently repeated my observations, and who furnished me much useful information and imported the valuable apparatus I employed. I am indebted to them for a full report of the labors of Ventzke, in Berlin, and of their own analyses of molasses, made in July, 1843. The relationship which subsists between us should not, I think, prevent my mentioning the valuable services of my younger brother, William J. McCulloh, who kindly undertook the laborious task of performing independently most of the calculations contained in this report, and discharged it faithfully; thus checking my work. Lastly, I would express my thanks to those gentlemen of the Treasury Department who have facilitated my labors, and particularly to Mr. Crabb, of the Comptroller's office.

I frequently use the terms *cane or crystallizable sugar, uncrystallizable sugar, left and right polarizing sugar, grape sugar, fruit sugar, starch sugar, liquid sugar, etc.*; and it is therefore fit that I should define the precise meaning of such terms, which I employ *technically*, espe-

cially as, in ordinary language, sugar is erroneously regarded as one substance, varying only in purity, color, and consistence.

A sweet taste and salt-like structure were sufficient in the days when accurate science had not cast its light upon the nature and properties of saccharine substances, to obtain for a body the name of sugar; and thus acetate of lead, composed of vinegar and the protoxide of lead, acquired the name of *saccharum saturni* or *sugar of lead*. Such loose employment of language is inadmissible in exact knowledge, and hence chemists have found it necessary to confine the application of the term *sugar* to such organic substances as have, superadded to a sweet taste, the property of being susceptible of alcoholic fermentation; there are a number of different substances which are therefore *sugars*, while some of organic origin and of very sweet taste, are excluded from the class because they do not undergo vinous fermentation. Such, for instance, as *mannite*, the principal ingredient of manna.

By *cane* or *crystallizable sugar*, chemists and refiners mean not only the extract of the juice of the sugar cane, but the same substance, however produced. The beet, the maple, the melon, the carrot, the turnip, and other roots, and the green Indian corn plant, all yield *cane* or *crystallizable sugar*, in greater or less proportion. Hence, *cane sugar* means that sweet substance which is susceptible indirectly of vinous fermentation; which, when pure, is perfectly white, crystallizes in prisms, and is of the specific gravity 1.6065; of which the chemical composition is carbon, hydrogen, and oxygen, the two last in proportions to form water; which, in solution, possesses the property of circular polarization of light, and the distinguishing feature, with relation to all other known sugars, of being invertible by acids without the aid of heat, and which behaves with chemical tests, and particularly the copper test of Trommer, in the manner described in the subsequent part of this report.

By *uncrystallizable sugar* is designated in contradistinction *any other* sugar than cane sugar. The distinction of *left* and *right polarizing sugar* will have no obscurity to any one who may read the succeeding chapter.

Besides cane sugar, and *lactine*, (milk sugar,) chemists agree in admitting the existence of another variety, to which M. Dumas has applied the generic name of *glucose*, but which Liebig and others have usually called *grape sugar*. Liebig includes under this head not merely the sugar of grapes and most acid fruits, but also sugar of starch, diabetic sugar, and all that class of sugars which are produced by the action of acids on vegetable fibre, such as paper and linen rags, or on cane sugar, sugar of milk, starch, &c. And it is in this extended though vague sense that I have frequently employed the term *grape sugar*, which in strict propriety should be confined to that sugar alone which is obtained from grapes. Yet Liebig remarks, that "although the identity of different kinds of sugar classed under the name of *grape sugar* or *glucose* be generally admitted, it is important to know that there are certain facts apparently irreconcilable with this notion." Also, M. Dumas says: "I believe that glucose will be found identical, whatever be its origin; whether from honey and fruits, or from diabetic urine, or produced by chemical action upon starch and ligneous fibre. But this opinion, in which chemists do not generally concur, can

* See *Traité de Chim. appliq. aux Arts*, t. 6, p. 274; Paris, 1843.

only be established (*entièrement justifiée*) by subjecting all these varieties to multiplied and very refined comparative tests." And, further, "*glucose*, properly so called, comprises, besides sugar of starch, that of diabetes, and perhaps agglomerated (*mamelonné*) grape sugar. It is necessary to observe, however, that glucose obtained from starch, whether by great pressure, and a small quantity of oxalic acid, or by the long-continued action of acids, differs in rotatory power from ordinary glucose."

Biot has shown* that both Liebig and Dumas have erred in giving to *glucose* or *grape sugar* too wide an interpretation, and that other chemists have gone further than M. Dumas anticipated, and applied his term *glucose* even to the saccharine product of cane juice under the influence of spontaneous fermentation, or of acids after saturation; to which product M. Bouchardat has given the name of *saccharo-glucose*. Biot shows that Liebig, in his Treatise on Organic Chemistry, by comprising under *glucose* diabetic, grape, starch, and fruit sugars, confounds liquid sugar of honey and liquid grape sugar with solid sugar of grapes, and the latter with sugar of starch; that, of all the distinct kinds of starch sugar which MM. Biot and Persoz found to exist, Liebig mentions but one; and that saccharo-glucose is by him confused with the sugar of grapes and sugar of starch; in short, that while the distinguished chemist of Giessen hesitated to pronounce all kinds of glucose identical, by reason of differences in points of fusion, he was "entirely without the thread of the labyrinth which optical properties only could have furnished him," and that of these he speaks loosely and inaccurately.

Glucose, or grape sugar, as it is more commonly called, of whatever origin, does not crystallize like cane sugar, in large regular crystals, but in minute fibrous crystals, the shape of which is not distinct, but which form tubercular masses. On this account, it is very frequently called by French writers *sucre mamelonné*. Its taste is at first farinaceous, then feebly sweet, and mucilaginous when it begins to dissolve in the saliva. Its sweetening power is only two-fifths of that of cane sugar; hence, in mixture with cane sugar, it greatly impairs the quality of the article for all domestic purposes. It is also much less soluble in water than cane sugar, and dissolves with difficulty even with protracted stirring; according to M. Baudrimont, water at 73° Fahrenheit is saturated by 0.635 of its own weight of grape sugar.

There is still a third class of sugars, which seem to exist only in the liquid state, and to pass into glucose when evaporated to dryness. Of these less is accurately known than of either of the preceding classes. These sugars have borne among chemists the name of fruit or liquid sugar; M. Soubeiran has proposed the term *chylariose* for them. M. Biot found that the sugar contained in fresh grapes differs from glucose in rotating the plane of polarization in the opposite direction. Cane sugar also, in solution, is converted by fermentation and acids into a peculiar sugar which polarizes to the left; and this sugar exists in large quantity in molasses which has been long made. Both of these liquid sugars are by evaporation converted into right-polarizing glucose, and cannot afterwards be made to polarize as at first to the left. M. Dumas remarks:† "Cane sugar forms a species perfectly distinct. We do not know in what consists

* See Comptes Rend. des Séances de l'Acad., t. XV, p. 636.

† See Traité de Chim., app. aux Arts, t. 6, p. 270.

the modification which renders it uncrystallizable in molasses, but it is beyond doubt that there exists a species of cane sugar which has been rendered uncrystallizable. Starch is converted by acids into a distinct sugar, which I call *glucose*; this may also become incapable of assuming the solid state; there is therefore an uncrystallizable glucose."

All these sugars are composed chemically, as are also gum, vegetable fibre, starch, &c., of carbon, hydrogen, and oxygen, the two last in proportions in which they form water; hence, chemical actions which deprive them of water, or impart it to them, convert often one into another. Sugar may be considered also as composed of carbonic acid, and alcohol, and very slight disturbance of the forces of attraction between their atoms will bring to pass this change of arrangement of their elements; such is the explanation of the phenomenon of *vinous fermentation*. Alcohol, by combining with the oxygen of the atmosphere, is converted readily into vinegar; hence the reason of the modern German process of allowing spirits to trickle through a pile of shavings, or of hay, thus exposing a large surface to the air, and quickly converting it into vinegar.

I have been thus minute in these preliminary remarks, that the difficulties of answering the question in the resolution of the House of Representatives, "what quantity of sugar is contained in different saccharine substances?" may be understood and appreciated by those who proposed that question; and that the propriety of the course pursued in these investigations, to attend chiefly to matters upon which the experience of the Government shows knowledge to be most requisite, may fully appear. Before the above-mentioned question can be directly answered, it should be stated, *what kind of sugar is meant*. In molasses, for instance, there are *at least two* kinds of sugar, 60 per cent. of good crystallizable cane sugar, and a large proportion of liquid sugar, mixed probably with grape sugar, (saccharo-glucose.) In raw or brown sugar there are contained, besides impurities, both cane sugar and grape sugar. So also much of the so-called refined sugar contains a large quantity of grape sugar, which constitutes a great impurity; for its sweetening power is two and a half times less than that of pure crystallized cane sugar. And such is the practical effect of this impurity, that, as I had recently occasion to learn, three pounds of pure sugar go as far in preserving fruits and other domestic uses as four pounds of the common or imperfectly refined loaf sugar of our markets; a fact which is important to be known in domestic economy, for the housewife's rule of "pound to pound" should be changed to three-quarters of a pound of sugar to every pound.

The necessity of investigating the distinctive properties of the different sugars, before Chemistry will have attained accuracy in this important branch of that science, will appear from the confusion which the preceding remarks will show to exist. It is no reproach to Chemistry, however, that such investigations have yet to be made, for as an exact science it is but half a century in age, while Organic Analysis is in its infancy, and most of those to whom we owe the first accurate analyses of organic substances, as well as the methods employed, are still in the prime of life and usefulness. The quantitative and beautiful method by the circular polarization of light is scarcely known generally to chemists; and it is perhaps the dawn of a new science, to which M. Biot has already given the name "Optical Chemistry." To the young analytical chemist it opens a wide and rich field of

research, and to the arts it has already yielded abundant fruit, while it bids fair to illumine many of the dark recesses of medical science.

SECTION I.

On the quantitative and qualitative analysis of sugars, sirups, and molasses, and particularly those derived from the cane.

1. Cane sugar is one of the numerous class of organic substances whose elements seem to be held together by chemical forces of very feeble intensity, so that very slight causes are sufficient to alter its nature and change it into entirely different bodies. By fermentation it is converted into mucilage, lactic acid, or alcohol and carbonic acid. The influences exerted upon it by heat, atmospheric air, and nitrogenous substances, are very powerful and important, constituting as they do obstacles to the planter and refiner, which they have earnestly but in vain endeavored to overcome. Science has been called to their aid with but little economical effect; and though of late years important improvements have been made, especially in refining, the principal difficulties in the manufacture of sugar are still unremoved. It will not, therefore, appear strange that the chemist has found his trouble, also, in the investigation of this substance; the agents which he usually employs in analysis, without so destroying the substance experimented upon that it may not be separated again unchanged, sever the elements of cane sugar so completely from their mutual combination, that it seems impracticable to reunite them; and, indeed, the present state of chemical science upon this subject goes far to show that it is scarcely more possible to reconstruct the atom of sugar, when once so destroyed, than it would be to restore the crushed plant from the mill to the condition in which it stood in the field. High rewards have been offered by Governments, and by the Academy of Sciences of Paris, for an exact chemical method of separating and analyzing the different varieties of sugar in mixture with each other or foreign substances. Such a method is yet undiscovered. Although that almost mathematical accuracy which the modern chemist is required to attain in his investigations, and which will not admit of errors in his weighings of even the thousandth part of a grain, has not been reached in the analysis of sugars, we possess methods which, for all practical purposes, are sufficiently precise, and which give earnest that exact chemical science will not long allow even this unstable substance to elude its skill. These methods will now be described.

2. If it be required to ascertain the quantity of sugar contained in a solution composed only of pure water and cane sugar, this may be done by four different methods, two of which are applicable to such solutions only, while the remaining two may likewise be employed when the solution contains other substances besides cane sugar. These four methods are: by evaporation, by specific gravity, by fermentation, and by the circular polarization of light.

3. *By evaporation.*—This is best performed under the receiver of an air pump, as heat, if protracted, will convert cane sugar into sugar not unlike

grape sugar, or that obtained from starch by the action of acids, diastase, &c.; but for practical purposes, evaporation of small quantities in a porcelain capsule, by a water bath, so that the heat may not exceed 212° Fahr., will give results of sufficient accuracy. The open flame of a lamp would be apt to burn or caramelize a portion of the sugar. When an air pump is employed, a vessel containing concentrated sulphuric acid should be used to remove vapor from the exhausted receiver.

In nice scientific investigations, it becomes important to fix the standard which shall be regarded as dry, solid, cane sugar. Brown sugars usually contain a large quantity of molasses and hygrometric moisture. And even pure white crystallized sugar exists in several states of aggregation, which vary in this respect; rock candy and loaf sugar, fine and coarse grained, more or less spongy in its texture, differ from each other, slightly it is true, yet sufficiently to exert an appreciable influence in very exact researches. Large crystals are apt to enclose portions of the mother liquor between their laminae; for this reason, rock candy, when perfectly white and transparent, is not a proper standard, unless it first be powdered finely and dried. Porous loaf sugar would also be an improper standard, on account of hygrometric moisture held between its crystals by capillary attraction. M. Biot, who had occasion to make a series of very nice researches upon this subject, takes as a standard finely powdered rock candy, perfectly white and pure, and dried by exposure for a long time to the ordinary atmospheric temperature in a dry room. If stove dried, or by means of an air pump, the hygrometric state would not be that under which sugar usually exists in commerce; and this, its mean or normal condition, is certainly that which should usually be understood as designated, when not otherwise expressly stated. In my own researches I have employed, as a standard, powdered loaf sugar, which had remained in a dry room for eighteen months, refined by J. S. Lovering & Co., of Philadelphia, by the vacuum process, and without the use of blood, eggs, or any other objectionable substance; the purity of which I ascertained by the most delicate tests; and I could not detect in it the slightest trace of foreign matter. The beauty of the sugar refined by this house exceeds that of any foreign sugar I have seen; and having been permitted to inspect their establishment, and carefully examine the process of refining there employed, through all its different stages, I feel assured that the sugar I adopted as a standard had been subjected to no action which could impair its perfect purity.

4. *By specific gravity.*—When sugar is dissolved in water, the solution becomes heavier, or possesses greater density; by mixing, therefore, accurately determined weights of water and sugar, in various proportions, and ascertaining experimentally the weight of a constant volume of each, tables may be formed which will tell by inspection the quantity of sugar contained in a solution whose density is either given or ascertained by means of an ordinary balance, according to the well-known methods, or with a hydrometer graduated to read specific gravities. Table I of the appendix constructed by Niemann,* and pronounced by Ventzke to be accurate, is intended for this purpose. It is adapted to the temperature of $63\frac{1}{2}^{\circ}$ Fahrenheit, ($17\frac{1}{2}^{\circ}$ centigrade,) but may be used for temperatures near to that; for a slight difference of temperature would only affect the fourth decimal

* See *Annalen der Pharmacie*, ii, p. 340.

place. As hydrometers graduated to read specific gravities are rare, costly, and of difficult construction, I give also table II, constructed by M. Payen, which shows the quantity of sugar for each degree of Beaumé (*pèse sirop*), the hydrometer usually employed by refiners and planters. As the instrument of Beaumé often varies, however, even by whole degrees, according to the skill and standard of the maker, it should always be verified by comparing it with the indications of solutions of sugar mixed for the purpose in the proportions of the table. A hydrometer might readily be constructed, the divisions of which should express the per centage of sugar in a solution; and such an instrument would be found simpler, and preferable to any other.

The use of hydrometers, though very convenient for pure solutions of crystallizable cane sugar, becomes inadmissible when grape sugar, molasses sugar, or other substances, are combined with it; for each substance dissolved affects the density, and it is impossible to distinguish the relative portion of the combined effect which is to be ascribed to the agency of each different ingredient. For this reason hydrometers will not determine the quantity of cane sugar in molasses.

5. Before stating the details of the methods by fermentation and polarization, as these methods are applicable to solutions containing other substances besides cane sugar, I shall give the tests to be employed in the qualitative analysis of sugars; the most delicate and important of which is the copper test of Trommer, as communicated by Mitscherlich to the Berlin Academy of Sciences.* The solution is treated with aqua potassæ, and then a dilute solution of sulphate of copper is added. Cane sugar becomes of an intense blue color; it may even be boiled with an excess of potash without separation of protoxide of copper, which occurs only after protracted boiling. When the experiment is performed without heat, the solution remains unchanged for several days, and protoxide of copper separates only after long boiling. A slight separation of protoxide of copper occurs, if it be allowed to stand a long while; but, even after several weeks, the reduction of the oxide of copper does not perfectly take place. If a solution of grape sugar and potash be treated with a solution of sulphate of copper, until the hydrated oxide of copper, which separates, is redissolved, after a short time, and at the ordinary temperature, protoxide of copper separates; if we warm the solution, *immediately* the protoxide separates, and the solution becomes colorless, even if a small quantity of sulphate of copper has been added. A solution which contains a hundred thousandth part of grape sugar gives, when boiled, a visible precipitate; and when it contains a millionth, by transmitted light the solution has a reddish color. We may by this test show that cane sugar, before it enters into fermentation, is first converted into a sugar resembling grape or fruit sugar. Milk sugar behaves with the copper test like grape sugar, but causes the reduction of oxide of copper to protoxide still more rapidly. The peculiar action of this copper test is due to the extreme facility with which all sugars, *except cane*, reduce salts of copper in their alkaline solutions, when raised for an instant to boiling. Owing to the fact that boiling converts cane into uncrystallizable sugar, which might be supposed to pre-exist, this test requires to be used with care; but its delicacy is indeed astonishing.

* See *Annalen der Pharmacie*. Liebig and Wöhler, vol. 39, p. 360.

With the copper test, a solution of gum gives a blue precipitate, insoluble in alkaline water, but soluble in pure water, which, when boiled, does not become black—a proof that the precipitate is not hydrated oxide of copper, which parts with its water and becomes black at 212° Fahrenheit; but that it is a combination of gum with oxide of copper. So likewise behave starch and gum tragacanth.

A solution of dextrine gives, without a trace of a precipitate, a deep-blue liquid, which, when allowed to stand a long time, does not change, but from which, if heated to 185° Fahrenheit, a red crystalline precipitate of protoxide of copper soon separates.

If to a solution of gum we add dextrine, we always obtain, besides a precipitate, a blue-colored liquid. Dextrine is therefore a distinct substance from gum. From this reaction we may readily be convinced that gum contains no dextrine. And when starch is converted, by nitric or hydrochloric acid, into dextrine; or by sulphuric acid, diastase, or animal membrane, first into dextrine, and then into grape sugar, the copper test shows that no gum is formed as an intermediate product. If a precipitate be obtained, it is still undecomposed starch, which is readily shown by a solution of iodine.

Cane sugar is readily distinguished from other sugars by the optical test of polarized light; for acids convert it, without heat, into a peculiar sugar, which polarizes from right to left, instead of from left to right; as for cane sugar, grape sugar, starch sugar, &c. And this property of being invertible by acids seems to belong to no other kind of sugar. Lime and alkalis, which do not alter the color of cane sugar, with the aid of heat render grape sugar dark colored. Cane sugar yields no precipitate either with the acetate or subacetate of lead, a property which enables us to separate many substances from its impure solutions. Absolute alcohol does not dissolve it to any extent, while it readily unites with liquid or uncrystallizable molasses sugar.

6. Upon these two last-mentioned properties depends the method followed by my friends Messrs. Booth and Boyé, for the analysis of molasses, and which I give as communicated by them to me. The results they thus obtained were embodied in a report made August 1, 1843, to Calvin Blythe, Esq., collector of the port of Philadelphia, and now on file in the Treasury Department, a copy of which (marked A) is also annexed.

In a bottle, carefully weighed, put about 150 grains of molasses and an equal weight of clean white sand, to render solution more easy by separating the viscid mass; then add the strongest alcohol of the shops, and digest the whole in a water bath for nearly an hour, repeatedly shaking the bottle, to dissolve the molasses sugar. The bottle is allowed to stand undisturbed for several hours, that the solution may become perfectly clear; and it is then decanted. After this operation of washing has been repeated twice or three times, the bottle and its contents are carefully dried by means of a water bath, and weighed. The loss in weight is the amount of uncrystallizable molasses sugar dissolved. The alcoholic solution may be evaporated and examined, to ascertain that it contains no considerable quantity of any other substance.

The residue in the bottle is dissolved in water, and filtered, to separate the sand. The extractive matter is then separated from the filtered solution by precipitation with subacetate of lead, carefully added, so that per-

fect neutrality may be obtained. The precipitate is collected upon a counterpoised filter, dried in a water bath, and weighed. The oxide of lead, separated from it by sulphuric acid, gives, by subtraction, the quantity of organic matter in its composition.

From the remaining solution, which contains cane sugar, we may obtain the quantity by fermentation, evaporation, or polarization.

This method, just described, I followed only in one instance, finding it more convenient to employ optical than chemical processes; but my experiments have served to convince me that neither should be adopted alone, to the exclusion of the other; and that certainty can only be obtained by their combined determinations, which should accord with and verify each other.

7. *By fermentation.*—If we mix yeast with a dilute solution of sugar, and allow the mixture to remain at a temperature of 80° to 90° Fahrenheit, after a short time fermentation will ensue, carbonic acid is disengaged, and alcohol formed. Thénard states that one part of yeast is sufficient for five of sugar; and the proportions of water and sugar which are best adapted to the transformation are, according to M. Colla, one of sugar to three or four of water. When there is but one of sugar to eight of water, the action is said to be too slow. In my own experiments I have employed solutions still more dilute without inconvenience.

Now, as the composition of cane sugar is very accurately determined, if it were converted entirely into carbonic acid and alcohol, we might ascertain the amount of either, and calculate the exact quantity of sugar from which it was formed. A small quantity of lactic acid is, however, produced at the expense of the sugar, which combines with ammonia from the decomposing ferment; yet the quantity of lactic acid is very small, if the fermentation be properly conducted; and as it is proportional to the nitrogen of the yeast employed, we might obtain a formula for calculating the sugar transformed into lactic acid from the weight of yeast. Sugar, under peculiar circumstances, undergoes a particular transformation, known as the *viscous* fermentation; but this never occurs when the process is conducted properly.

From the preceding it will appear that analyses of sugar, by fermentation, though not rigorous, are yet sufficiently accurate for practical purposes. Pelouze, in his investigations of the juice of the sugar beet, determined the quantity of sugar contained by the alcohol yielded in fermentation. But it is easier to ascertain it from the carbonic acid, the quantity of which may be measured over mercury or obtained by loss of weight; the latter is preferable. For this purpose, the usual apparatus, consisting of a flask or bottle, fitted with a chloride of calcium tube, is employed. The sugar or saccharine substance is first accurately weighed, then introduced into the flask, and dissolved in a considerable quantity of water; a small portion of yeast being added, the whole is weighed. The moisture which accompanies the carbonic acid is absorbed and retained by the chloride of calcium. After the fermentation has ceased, the carbonic acid remaining in the bottle must be expelled, by sucking atmospheric air into it with a tube; and then the apparatus should be again weighed; the loss of weight is the quantity of carbonic acid which escaped. Now, every 100 parts, by weight, of carbonic acid, correspond to 195, nearly, of cane sugar; we therefore determine the latter when we ascertain the weight of the former. During the fermentation, the mixture is apt to froth and swell

up, so as even to find its way through the chloride of calcium tube, and thus cause a failure of the operation. I have found a small quantity of olive oil floating on its surface, which I tried at the suggestion of my friend M. H. Boyé, an effectual preventive of this accident. For the qualitative analysis of sugar, M. Quevenne has shown that fermentation is a very delicate test; yet it is inferior to the copper test.*

8. *By circular polarization.*—To a remarkable optical phenomenon, discovered by Arago in crystallized quartz cut perpendicularly to its axis, and also by Biot in liquids of vegetable or animal origin, Fresnel has given the name of *circular polarization*. Biot has investigated the subject with remarkable skill and success, and furnished to the chemist a means by which he may impress light, that most subtle and intangible of the agents of nature, into his service, and substitute it for the balance in determining weights of organic matter with all requisite accuracy—a discovery as singular as it is beautiful.

When a ray of ordinary light is transmitted through a rhomboid of Iceland spar, or any crystal which does not belong to the regular system with three equal rectangular axes of symmetry, it will, in almost every direction, be divided into two rays of equal intensity, refracted at different angles, one in the plane of incidence, the *ordinary ray*; the other in a different plane, the *extraordinary ray*. If it comes from a luminous body, as for instance a candle, then an eye looking through the crystal will behold two images of equal brilliancy. This is the property usually spoken of as that of *double refraction*. If the crystal be revolved in a plane at right angles to the ray as an axis of rotation, then will the images appear to revolve round each other, but their intensity will not vary.

If, however, the ray be one which has already passed through a doubly refracting crystal; or which has suffered reflection from a polished surface of glass at an angle of $35^{\circ} 22'$, then will it possess peculiar properties, to which Malus, their discoverer, has given the name of *polarization*. If a ray of polarized light be transmitted through a doubly refracting crystal, it is divided into two rays of *unequal* intensity, or an eye would behold two images of *unequal* brightness. Let i be the incident ray, x the angle formed by the principal section of the second crystal with that of the first, or with the plane of reflection, o the ordinary ray, and e the extraordinary; then will

$$o = i \cos.^2 x, \quad e = i \sin.^2 x,$$

the sum of which is always equal to i , the incident ray. When $x = 0$, or $x = 180^{\circ}$, then $o = i$ and $e = 0$. And when $x = 90^{\circ}$, or $x = 270^{\circ}$, we have $e = i$, and $o = 0$. Hence, at each quadrant, the ordinary and extraordinary ray alternately disappear, and these two rays are always complementary to each other.

Of doubly refracting crystals, some are symmetrical about one particular line of figure, others unsymmetrical; they thus constitute two distinct classes. If a face be cut any where upon these crystals, a ray of light falling perpendicularly upon it will generally suffer double refraction. But for crystals of the first class, there is one position of the plane or face, for

* See Journal de Pharmacie, t. xxvii, p. 589.

which the normal ray is transmitted without division; while for crystals of the second class, there are two or more such positions. The normal ray for such planes is called an *optical axis*, and crystals are consequently distinguished as *crystals of one axis* and *crystals of two or more axes*.

When a normal ray of homogeneous polarized light falls upon a plate of a doubly refracting crystal of one axis, cut perpendicularly to that axis, it is transmitted unchanged. To this law quartz presents the only exception among crystallized bodies; and it is to the peculiar phenomena presented alike by this substance and certain organic liquids, under such circumstances, that the term of *circular polarization*, or *rotation*, is applied. The ray which has passed through them remains polarized, but its plane of polarization has revolved about the axis; plates cut from some specimens of quartz cause it to revolve *to the right*, from others *to the left*. In that variety of quartz which Haüy called *plagiedral*, the inclination of the plagiedral faces has been discovered, by Sir John Herschel, to determine and be intimately connected with the direction of the rotation. So likewise liquids cause rotation, some to the right, others to the left. The more refrangible rays of the spectrum have their planes of polarization displaced the most; thus the plane of the red ray, when that ray is transmitted through a plate of quartz one millimetre in thickness, will deviate, according to Biot, by an angle of $17^{\circ} 29' 47''$; while the plane of the more refrangible violet ray will rotate through $44^{\circ} 4' 58''$. Hence, a ray of white polarized light will be decomposed into rays of every color polarized in different planes. Biot has shown that the angle of deviation for each homogeneous ray will vary proportionally to the thickness of the stratum of liquid through which it passes; and that the angles of deviation for the different colors will, for each respective thickness, be to each other in constant ratios; which ratios Biot finds also to be the same for every active substance, except tartaric acid and its combinations.* The foregoing facts will render the terms employed of distinct signification, and at the same time serve to explain more fully the phenomena upon which the method of chemical analysis by circular polarization depends.

In the year 1815, M. Biot communicated to the Academy of Sciences the discovery that certain liquids, such as essence of turpentine, oil of citron, spirits of camphor, &c., possess the property of circular polarization. And the previous investigation which he had made of the laws of that phenomenon, as presented in quartz, prepared him to seize upon its more hidden and feeble indications in liquids.

Yet it was not before 1832 that he had brought his apparatus and methods to the degree of perfection requisite for organic chemical analysis. By a series of researches, made with the greatest care, M. Biot arrived at the following laws.† *The angle of deviation for each ray of homogeneous light is proportional to the length of the tube or stratum of liquid it contains, the density remaining constant. It is proportional likewise to the number of active particles in the liquid.*

A pure solution of cane sugar, containing ten per cent. of sugar, will rotate the plane of polarization through twice the angle produced by one of five, the length of the tube being the same; nor will this angle vary if the solution be diluted with water, or any other inactive substance, such as alcohol, sulphuric ether, &c., if we increase the length of the tube in the

*Memoires de l'Académie, t. xv, p. 95. Ibid, ii, p. 58.

† Memoires de l'Académie, t. xiii, p. 116; t. xv, p. 100; t. xvi, p. 241.

same ratio. Biot found that spirits of turpentine reduced to the state of vapor at rest or in motion, or liquid and violently agitated by a mechanical contrivance moved by clock work, still retained its polarizing power unaltered. And if liquids polarizing in opposite directions be mixed, in quantities inversely proportional to their rotary powers, then will their effects be mutually destroyed, and the plane of polarization remain undisturbed. Hence it follows, that circular polarization does not depend upon relations of symmetry or position of masses; that it depends upon the nature of the molecules themselves, and therefore is one of the characteristic properties of the substances which possess it; and that the total or integral angle of deviation of the plane of polarization for any given ray is the sum of all the infinitely small deviations produced by the molecules.

The *molecular rotary power* of a substance is therefore one of the constants of its nature. For different substances, this constant is either positive, *to the right*; or zero, *molecularly inactive*; or negative, *to the left*. Let (α) represent the molecular rotary power of an active substance; for instance, of crystallizable cane sugar. Then it is evident, from the preceding, that

$$(\alpha) = \frac{a}{l \varepsilon \delta} = \frac{a'}{l' \varepsilon' \delta'} - \dots - (1);$$

In which a, a' are angles of deviation for a particular ray, e. g. the violet blue, as observed through tubes of the respective lengths l and l' ; and for solutions of the densities δ and δ' containing the proportions ε and ε' of active matter. This is Biot's formula for the rotary power of solutions containing only one kind of active matter, and it is evidently adapted to logarithmic computation.

To render this formula more general and convenient in chemical operations, suppose the solution somewhat colored, sufficiently so to render it impossible for the naked eye to decide the tone of color produced by circular polarization. Then, by means of colored glasses, red, green, or yellow, we may still obtain the deviations of their respective planes, which it may be required to reduce to the corresponding deviations of the violet-blue ray, as they would have been observed by the naked eye if the solutions were perfectly colorless. Now, as stated above, the deviations of different colored rays are to each other in constant ratios, except for tartaric acid; hence, let m be the coefficient by which we must multiply the observed angles of deviation to reduce them to the angles which would have been observed for the red ray, or through a glass transmitting only homogeneous red light, which glasses colored with protoxide of copper are found to do. Then

$$(\alpha') = \frac{m a}{l \varepsilon \delta}$$

is the general formula for deviations of the red ray, taken as a standard of comparison; * in which $(\alpha') = m (\alpha)$ is the rotary power for the unit of substance, and for the red ray.

* See Comptes Rendus des Séances de l'Académie, t. xv, p. 619.

The analytical chemist often finds, in his investigations of organic bodies, that substances exist in solution which cannot be separated without destroying them, or without admixture or combination with other ingredients. It is in such instances especially that the method of analysis by circular polarization has its greatest advantages. For, then, if the substance he would isolate possesses rotary power, and is the only active matter in solution, he may entirely disregard the substances with which it is mixed. On this account, distilled or pure water is not required, and even water highly impregnated with mineral substances may be used, provided it possesses no chemical power to change the nature of the substance to be dissolved in it.

Biot has found that solutions of cane sugar, and of sugars generally, whether mixed or separate, may, as far as their optical properties are concerned, be regarded as simple mechanical mixtures. To ascertain this, they were dissolved in very different and numerous proportions, and the angles of deviation observed were found to be exactly proportional to the quantities of active matter in solution. So determinations of per centage by this method possess all the accuracy attainable for other substances by means of a delicate balance.

As (α) and $(\alpha') = m(\alpha)$ are constants, for each chemical substance, too much care and nicety cannot be spent upon their exact determination; and this once done with the required accuracy, need not be afterwards repeated. If by rigid observations we have obtained (α) for the violet-blue ray, and (α') or the coefficient m for the red ray of the protoxide of copper glass, we have by equation (1)

$$\epsilon \delta = \frac{a}{l(\alpha)} = \frac{m a}{l(\alpha')} \quad (2).$$

The density δ is observed by the well-known methods for taking specific gravities, and l is measured. Hence ϵ is the only unknown quantity in equation (2), and is determined by it. To explain the precise meaning of the first member of this equation—the value of which is given by the second, which contains only known quantities—if the half-pint measure be defined as that which contains, at $56\frac{1}{2}^{\circ}$ Fahr., the one-hundredth part of a cubic foot of water, and weighs ten ounces troy; and if the densities be either taken at, or reduced by calculations to, this temperature, for which that of distilled water is assumed to be unity; then as ϵ is the unknown per cent. of active matter, in each unit by weight of the solution, and δ represents the weight in ounces of a half pint of the solution, $\epsilon \delta$ will represent the quantity in ounces of the active substance contained in a half pint of the solution; and if we multiply by 480, we shall reduce this to grains. It is evident that δ need not be known except to obtain ϵ , the per centage; and that $\epsilon \delta$ will, for practical purposes, often be sufficient.

If we make $c = \frac{1}{(\alpha)}$, and $c' = \frac{1}{(\alpha')}$, then equation (2) gives

$$\epsilon \delta = c \frac{a}{l} = c' \frac{a'}{l};$$

where α' , the angle observed directly with the red oxide of copper glass, is equal to α , the angle of deviation of the violet-blue ray, multiplied by

m , the constant coefficient. For the glass which he employed, M. Biot has found m equal to $\frac{2.3}{3}$; by which quantity, therefore, all observations of the violet-blue ray are to be multiplied, to reduce them to Biot's red ray. By very exact determinations, M. Biot finds for cane sugar $c = 1.4$, and $c' = 1.827$. So that

$\varepsilon \delta = 1.4 \frac{a}{l}$, for the violet-blue ray; and

$\varepsilon \delta = 1.827 \frac{a'}{l}$, for the red oxide of copper glass.

9. One of the applications of this method is to observe the quantity of diabetic sugar contained in the urine of persons afflicted with the peculiar disease which produces it. Biot finds diabetic sugar given to him by M. Pélignot in 1836 identical with that presented by the same person in 1840, and also with another specimen obtained from M. Bouchardat, and gives for diabetic sugar the formulæ

For the violet-blue ray, $\varepsilon \delta = 2.176 \frac{a}{l}$,

For the red ray, $\varepsilon \delta = 2.838 \frac{a'}{l}$,

For minimum intensity of light, $\varepsilon \delta = 2.34 \frac{a''}{l}$.

10. Hitherto, we have supposed the solution to contain only one active ingredient; now, let it contain unknown quantities of crystallizable cane sugar mixed with uncrystallizable sugar, or any other substances, the rotary power of which, if they have any, is not altered by acids, without the application of heat; then, may the quantity of crystallizable cane sugar still be readily determined by the use of acids.

M. Biot has found that the stronger acids generally, when introduced cold into solutions of crystallizable cane sugar, invert the polarizing power, or cause them to rotate from right to left, instead of from left to right. And this seems to be a property belonging to cane sugar only. All other sugars remain unchanged under the influence of cold acids. Certain varieties of starch sugar, when boiled for a long time with dilute sulphuric acid, suffer peculiar and sudden losses of rotary power, which, always directed to the right, at last attains a minimum deviation, at which it remains constant.

In the gum of the acacia, we have an example of inversion by sulphuric acid: the rotary power directed from right to left, gradually travels to the right, with the separation of a precipitate. But neither of these exceptions can be confounded with the inversion by cold acids for cane sugar.

To an aqueous solution of cane sugar add hydrochloric or sulphuric acid, taking care that it be generally diffused, and not allowed to concentrate its action upon small portions of the whole mass, so as to carbonize them. The deviation to the right will diminish, become gradually reversed, and at last attain a maximum to the left, at which it will be constant. With hydrochloric acid, even one-tenth or eleventh, by volume, will effect this maximum deviation in a few hours. One or two days produce no change, but a more prolonged action causes the solution to become yellow; and

afterwards the inverted deviation grows weaker, until the mixture ceases to be transparent. For observations of colorless solutions with this acid, M. Biot finds, if we employ the violet-blue ray of the transition from dark blue to orange red in the extraordinary image, that the inverted deviation at its maximum is constantly at 0.38 of the primitive deviation; each being observed for an equal thickness and state of dilution, or reduced to such by calculation. For sulphuric acid, this ratio is somewhat greater, and amounts to 0.3867. The progress of the inversion also is slower, unless the temperature be raised to 140° Fahr., in which case it attains the maximum of inversion almost instantaneously, and without becoming colored.

Fermentation inverts the rotary power of cane sugar, while the other sugars preserve the direction of their rotary power under its action. Yet Soubeiran has shown that inverted cane sugar rotates to the left only while in the liquid state; in solidification, it regains its direction to the right, and is not afterwards invertible by acids. On the behaviour of cane sugar with acids, under all the various circumstances of temperature, relative quantity, &c., M. Biot has made an extended series of researches; and though it is two years or more since he promised them to the scientific world, they are not yet published.*

To analyze a mixed solution, therefore, observe its primitive deviation; then dilute it with a known volume of hydrochloric acid, and, allowing sufficient time for the inverted deviation to attain its maximum, observe the angle again. The change produced will enable us to deduce the per centage of cane sugar in the original mixture, as it is due to it only.

11. To obtain a formula for this purpose, let x be the unknown per centage of cane sugar in each unit by weight of the mixture—for instance, in an ounce or grain—then p ounces will contain $p x$ of cane sugar; and p is taken by a delicate balance; mix it then, if necessary, with e ounces of distilled water. Then in this solution the proportion by weight of the primitive mixture is

$$\varepsilon = \frac{p}{p + e};$$

And the quantity of crystallizable cane sugar is

$$\varepsilon' = \varepsilon x = \frac{p x}{p + e} \quad (3).$$

Denote by α' the primitive deviation for a particular refrangible ray, and by α'' the inverted deviation for the same length of tube and state of dilution. Let $-r''$ be the ratio of inversion, so that $\alpha'' = -r'' \alpha'$. For pure crystallizable sugar, this ratio, which we will call $-r'$, is equal to 0.38 when hydrochloric acid is used.

Let S be the portion of the primitive deviation produced by the cane or invertible sugar, and D the remaining portion, produced by the sugar which is not invertible. D is additive to S , or positive, if the uninvertible sugar act to the right; and negative, if to the left; but the calculations show its sign as well as its value. As α' is equal to the sum of S and D ; and as the

* See Comptes Rendus des Séances de l'Acad., t. xv, pp. 534, 697.

inverted deviation α'' is equal to S , changed by inversion to $-r' S$, plus D remaining constant, we have

$$\left. \begin{aligned} S + D &= \alpha', \\ D - r' S &= \alpha'' = -r'' \alpha'. \end{aligned} \right\} \quad (4).$$

Eliminating, we have

$$\left. \begin{aligned} S &= \frac{1 + r''}{1 + r'} \alpha' = \alpha' + \frac{r'' - r'}{1 + r'} \alpha'; \\ D &= -\frac{r'' - r'}{1 + r'} \alpha'. \end{aligned} \right\} \quad (5).$$

In these equations r' is always in itself positive, because acids invert the primitive deviation of cane sugar. If the inverted deviation of the mixture also passes really to the left, then will r'' be likewise essentially positive. But if it remains to the right, and merely weakened, r'' will be negative. Observing this rule of the signs, calculation will always give S and D , and the signs of their values will show their directions, to the right, if positive, and to the left, when negative.

Now the deviation S , observed through a tube of the length l , is produced by the cane sugar in the solution, of which δ is the density and ϵ the proportion by weight. Hence, by equation (1)

$$(\alpha) = \frac{S}{l \delta \epsilon'} = \frac{S}{l \delta \epsilon x} \quad (6).$$

In this equation, x is the only unknown quantity; and, therefore,

$$x = \frac{S}{l \delta \epsilon (\alpha)} \quad (7).$$

Let (β) be the rotary power of the primitive mixture, since it produces the deviation α' through the tube l , for the density δ and proportion ϵ , we have, by equation (1),

$$(\beta) = \frac{\alpha'}{l \delta \epsilon}; \text{ and therefore, } x = \frac{S (\beta)}{(\alpha) \alpha'}.$$

To verify this formula, we may apply it to cane sugar alone; for which, $D = 0$, and $S = \alpha'$, and all the active matter having the ratio of inversion equal to -0.38 , we get $r'' = r'$. If, then, standard sugar be identical, both in purity and hygrometric condition, with that used in the experiment, $(\beta) = (\alpha)$ and $x = 1$; if the former be drier than the latter, then will it also be more active and (β) will be less than (α) ; if less dry, (β) will exceed (α) . This verification likewise serves to test the delicacy and exact-

ness of the method. The algebraic formulæ for S and D also show that any small errors of observation enter into their values affected by the denominator $1 + r'$, in which r' is necessarily positive, and which therefore exceeds unity.

12. There are several methods of determining angles of deviation ; of these, the best is probably that of observing the violet-blue ray. From the law according to which the different rays are dispersed, Biot has been able to show that this violet-blue tint in the extraordinary image corresponds with the deviation of the simple yellow rays, and that it is also the point of minimum intensity. Hence, the deviations are comparable, as for a simple ray; and the second peculiarity allows the deviation to be observed when the image is too feeble to discern its color. For perfectly colorless solutions, whether transparent or slightly opalescent, this method is therefore accurate, convenient, and adapted to the naked eye. To observe the violet-blue ray, turn the analyzing prism about the transmitted ray as an axis; as it revolves, the blue will become more and more dark, until it changes, almost abruptly, to orange red; these two colors are separated only by a violet blue or bluish violet; and it is at this momentary transition color that the motion of the prism is arrested. The angle of deviation is then read off upon the graduated limb. The suddenness of this change, and strong contrast of colors on either side, removes all uncertainty arising from peculiarity of eyes in different individuals. From childhood I have been aware of a constitutional defect in my own eye with reference to the perception of certain colors in the spectrum ; it seems to be a partial insensibility to red light ; and colors appear to me nearly as described by Mr. Dalton in the Manchester Memoirs. I was therefore apprehensive, before experimenting upon the subject, that I should be unable to determine angles of rotation with accuracy ; but I found by repeated trials that independent observations of the violet-blue ray, made for transparent colorless solutions by my friends Messrs. Booth and Boyé, did not differ from each other, nor from mine, the quarter of a degree, a quantity which in these observations may be disregarded, as it would not produce a personal equation greater than those which usually affect chemical analyses. And I am confident that practice would have enabled us to have reduced even this difference to the tenth of a degree, within which the graduation of the limb would not admit of reading ; for our later observations scarcely exceed that amount in variation, and they were made without knowledge of previous readings on the part of the observer. The means of a number of observations would not, perhaps, differ by an appreciable fraction.

The method of minimum intensity is rendered more exact by observing azimuths of disappearance and reappearance of the image ; their mean result will not vary appreciably with considerable fluctuations of the light, whether it be that of a candle or the sky. This method I have employed with satisfactory results.

But, for observations of colored solutions, no method is, probably, so convenient and accurate as that of using an eye piece of colored glass ; and particularly of that kind of glass which is stained with the protoxide of copper, which transmits of white light rays so nearly alike in refrangibility that the eye perceives no sensible difference of shade. The thicker the glass, the simpler the color, and the nearer it approaches the extreme red of the spectrum. But, as the quantity of transmitted light diminishes in propor-

tion to its purity, we soon attain a limit of thickness, beyond which the intensity becomes too feeble. To determine the suitable degree of thickness, refract the light of a candle through a dispersive prism; then place the glasses to be examined between the eye and the face of emergence, and select those which transmit only a red image. This red, though not rigorously simple, is yet so nearly so that it will be but slightly dispersed, if the angles of deviation be limited to arcs less than a quadrant; and they need not be greater.

To render the observations more exact for the small arc of non-appearance at the point of minimum intensity, observe the azimuths of disappearance and reappearance of the image, and take their mean. The deviation of the violet blue ray is fixed in nature; but observations of the red ray will vary with the glass employed; and each observer should therefore determine the coefficient m of the particular glass he uses, by which his researches will be rendered comparable with those of other persons. For this purpose, he may employ a transparent solution of cane sugar; the percentage, the density, and the length of the tube, need not be known; but the angles of deviation for the violet-blue and the red ray of his glass must be observed repeatedly, and with the utmost care; the mean determinations will give m , the coefficient sought. Although the red oxide of copper glass is the only kind yet known, for a slight thickness, to transmit homogeneous light, green glasses, stained with oxide of chrome, and some of an orange color, when of somewhat greater thickness, may be substituted; for observations of organic solutions of an orange color, an orange glass is very well adapted. I have to regret that I have not yet been able to procure an oxide of copper glass; and the green, blue, yellow, and orange glasses, of which I have tried a large number, when examined by means of a dispersive prism, have proved to be very deficient in their power to transmit homogeneous light without great loss of intensity. But little colored glass is manufactured in this country, and scarcely any into forms which would answer for these experiments.

There is still another method, that by comparison of color, adopted at the suggestion of Marchand, and highly recommended by Ventzke,* through a tube containing an aqueous solution of anilate of iron, and transmitting orange-red light, observe the same luminous body which is viewed through the rotating solution; when the colors are of the same tone, read off the corresponding angle. Whatever may be the cause, I have hitherto found it wholly impracticable to arrive at accurate results by this method; nor do I think it owing solely to the defect in my eye above mentioned; for, though Messrs. Booth and Boyé did not often vary more than one or two degrees, yet sometimes they differed five or more. And a scientific friend, who has no peculiarity of eye with regard to color, and great experience and skill as an observer, varied even ten degrees in his readings for the same solution. It is very difficult to render the light of equal intensity in the two tubes; and the anilate of iron seems to undergo decomposition, as a precipitate separates in the tube. Of this method, therefore, I hesitate to decide, or pronounce any opinion, without giving it another and a fairer trial.

13. Those who would pursue researches in Optical Chemistry must make themselves thoroughly acquainted with the details and principles of con-

* See Journal für Praktische Chemie, vol. xxv.

struction of the apparatus employed. These they will find fully and clearly developed, together with all necessary information respecting manipulations, in the papers of Biot, to which I refer.* For more general information, I will now endeavor briefly to describe his apparatus, as well as that of Ventzke, which I have used; and to which, from comparison with an instrument of M. Biot, of very superior workmanship, made, I believe, by M. Soleil, of Paris, for J. S. Lovering & Co., of Philadelphia, I give a decided preference. The apparatus I used was imported, with a similar one for their own use, by Messrs. Booth and Boyé, and was made by Maywald, in Berlin; the workmanship appears to be excellent. It is also accompanied by two hydrometers for taking densities, and a thermometer, by J. G. Greiner, of Berlin; which are of remarkable delicacy and beauty.

The apparatus of M. Biot is very simple; it consists essentially of a polished black glass plate A, to reflect the light at the angle of Malus (see Fig. 1) of a tube suitably inclined to receive the polarized ray and contain the liquid B; and a prism of Iceland spar, achromatized by removing a portion of the crystal and substituting glass in its place, and attached at the centre of a graduated limb to an alidade C, in such a manner as to be susceptible of adjustment in azimuth. The whole is firmly attached to proper supports. The observer should place himself in a dark room, to render his eye more sensible to delicate impressions, and shut out all light except that which passes through the tube.

The apparatus of Ventzke is not much more complicated, and is composed of two doubly refracting prisms of Iceland spar, (see Fig. 2), an analyzing prism A, fixed, as M. Biot's, to a movable alidade at the centre of a graduated limb, and a polarizing prism B, of which, by motion about the ray as an axis, the principal section may be nicely adjusted by a tangent screw C, to a position at right angles to that of B, when the index points to zero upon the limb, and the intensity of the ordinary ray becomes $i \cos.^2 x = i \cos.^2 90^\circ = 0$, or perfectly dark. The intense light of the sun's direct ray is used to fix this zero point. Between these prisms the tube D is placed, which contains the solution; and its ends are closed with glass discs. The light employed is that of an argand lamp. The doubly refracting crystals are Nicol's prisms; they are made by grinding the rhombohedron of calcareous spar until its terminal planes form angles of 68° with its obtuse lateral edges. It is then cut diagonally and at right angles to the new planes. The crystal so divided is joined together again by Canada balsam, whose index of refraction, 1, 55, lies between that of the ordinary ray, 1, 65, and that of the extraordinary ray, 1, 48, and operates upon the two rays in opposite directions, separating them so widely that the extraordinary image may be made to disappear. The polarization by this prism is much more complete than by reflexion, and the light is much more intense; the limited field of vision is the only objection. Ventzke's apparatus is far more compact and transportable than Biot's, and is therefore much more convenient for general use. To adapt it to the wants of practical men, refiners, planters, and others, and avoid all calculations, Ventzke has computed tables, and attached to the graduated limb a pinion which turns a wheel fastened to the analyzing prism and the alidade. Upon a disc A, (Fig. 3,) firmly united with the pinion, the per centage is read

* See, particularly, *Ann. de Chim. et de Phys.*, t. 64, p. 401; also, *Comptes Rendus*, 7. Septem., 1840.

off directly for solutions of the normal density of 1.1056 at $63\frac{1}{2}^{\circ}$ Fahrenheit, and with tubes of the normal length of 234 millimetres. By means of his tables, densities observed at other degrees of the thermometer may be reduced to the normal temperature.

As Ventzke has not given the calculations and experiments upon which he bases his tables, I prefer to employ the method and formulæ of M. Biot, even though it involve some calculation.

In the thirteenth volume of the *Memoires de l'Académie*, M. Biot gives a table for solutions of cane sugar, which I annex, (see table 3;) but I prefer to use his formula, as that table was constructed with data taken from his earlier and less exact determinations.

Analysis of several specimens of molasses by the circular polarization of light.

14. To take the specific gravities of these substances, I found none of the usual methods for liquids well adapted; in several of them there were considerable deposits of sugar or other solid matter; to arrive at mean results, these deposits had to be stirred up from the bottom, and mixed intimately with the fluid portion, so as to form a homogeneous mass. In doing this, a large number of small bubbles of air become entangled in the viscid mixture, which will not all escape until it has stood quietly for twenty-four hours. The use of the *pèse sirop* of Beaumé is therefore impossible, for it would either be affected by the bubbles of air, or give no indications for the solid matter. A specific gravity bottle was found objectionable on account of the impracticability of removing air bubbles from the neck. I found a surgeon's cupping glass, ground so as to fit tightly upon a small disc of plate glass, to answer every purpose. It could be filled perfectly with water or molasses, and even washed and wiped with a towel until dry, if carefully done, without loss or accident; and the glass disc would, of itself, adhere so closely as to render it liable to no risk of slipping while upon the balance.

The cup and disc were found to weigh 1107.8 grains; filled with water, it weighed 2328.7 grains.

Therefore, 1220.9 grains is the weight of the water alone; $\log. 1220.9 = 3.0866801$, which is the constant logarithm to be subtracted from that of the weight of an equal volume of each specimen. The accompanying table contains the data and corresponding results:

Molasses.	Weight in grains. γ .	Log. γ .	Difference of logs.	Specific gravity.
No.				
1	1713.2	3.2338081	0.1471280	1.4032
2	1703.6	3.2313676	0.1446875	1.3953
3	1674.8	3.2239630	0.1372829	1.37176
4	1661.	3.2205003	0.1348202	1.36089
5	1710.8	3.2331992	0.1465191	1.40126

15. The following are determinations by Ventzke's tables for the quan-

tity of water; obtained by observing the densities of solutions composed of three parts by weight of molasses and seven of water:

Molasses.	Specific gravity of aq. solution.	Temperat. centigrade.	Per cent. of water.	Per cent. of solid matter.
No.				
1	1.1014	15.	20.32	79.68
2	1.0985	17.3	22.04	77.96
3	1.094	20.	24.9	75.1
4	1.088	15.	30.5	69.5
5	1.100	12.	21.7	78.3

The specific gravities were taken by a hydrometer made by J. J. Greiner. The fifth column is obtained from the fourth, to which it is complementary.

The analyses by Ventzke's tables, if we use the observed angles of deviation for the anilate of iron, would therefore be:

Molasses.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Cane sugar -	57.37	51.14	50.67	45.17	59.9
Liquid sugar	22.31	26.82	24.43	24.33	19.4
Water -	20.32	22.04	24.90	30.5	21.7

The angles are those of the following data.

16. Equal parts by weight of molasses and water were filtered through bone black, contained in displacement tubes of lengths varying from one to three feet, until perfectly decolorized; by adding water, the colorless solutions were brought to the normal density 1.1056 at 63½° Fahrenheit; they were then observed through tubes of the normal length of 234 millimetres, with the results of the table:

Observer.	Booth.	Boyé.	McCulloh.	Means.	Booth.	Boyé.	McCulloh.	Means.
Molasses No.	Violet ray.	Violet ray.	Violet ray.		Anilate of iron.	Anilate of iron.	Anilate of iron.	
1	24.5	24.25	24.5	24.41	74.?	68.?	74.?	72.?
2	.....	25.83	25.75	25.79	.....	66.	65.?	65.5
3	23.	23.	23.	23.	69	68.5	69.?	68.8
4	24.25	24.75	25.5	25.5	66	64.	?	65.
5	28.20	28.25	28.15	28.15	76	77.	?	76.5

17. To compare the results of these different methods, I formed a solution containing 25 per cent. by weight of pure crystallized cane sugar, and found it of the normal density. This solution (Ventzke's normal solution) should

read for the anilate of iron 56° or on the pinion disc 100 per cent.; which I found to be the case for the eyes of Messrs. Booth and Boyé, as well as for my own. The violet ray was observed by Mr. Boyé and myself, with the same result, 42° or 75 per cent. on the disc. The coefficient by which we must multiply the means of the violet ray, to reduce them to those of the anilate of iron ray, is therefore $\frac{100}{75}$. The following table gives the comparison:

No.	Violet.	Violet reduced.	Per cent. by anilate of iron ray.		
	α	$\frac{100}{75} \alpha$	Calculated.	Observed.	Difference.
1	24.41	32.55	58.	72.	14.
2	25.79	34.38	61.75	65.5	3.75
3	23.	30.66	55.	68.8	13.8
4	25.5	34.	61.	65.	4.
5	28.15	37.53	67.	76.5	9.5

The differences in the last column of this table are so large that they establish the fact that no accuracy can be attributed to the observations made with the solution of anilate of iron employed in these experiments. The following analyses, obtained from the *calculated* per cents of the preceding table, are more entitled to credit, as they depend upon the accordant observations of the violet ray:

Molasses.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Cane sugar -	46.21	48.21	40.50	42.39	52.46
Liquid sugar	33.47	29.75	34.60	27.11	27.84
Water -	20.32	22.04	24.90	30.50	21.70
Total -	100.00	100.00	100.00	100.00	100.00

These results also seem at first to agree with certain analyses of Biot and Soubeiran. In good sugar-house molasses, Biot has found 40 per cent. of crystallizable cane sugar; while Soubeiran, from many specimens, gives as the amount of cane sugar in molasses 50 per cent., after deducting the water. If we compute the water at 20 per cent., then we will have 40 per cent. as the proportion; and this is the result of M. Biot. Ventzke has found as much as 60 per cent. by the use of the comparison tube of anilate of iron.

It is extremely difficult to render aqueous solutions of molasses perfectly colorless by the use of bone black; there is a yellow tint, which in some cases, it seems almost impossible to remove, and which, when viewed through a tube 234 millimetres in length, is sufficiently deep to affect very materially any results by comparison of color. The bone black I employed was of very superior quality. Yet several of my solutions, though

filtered five or six times through thicknesses of two or three feet of fresh bone black, obstinately refused to part with the yellow tint above mentioned.

The specimens of molasses, which I have called Nos. 1, 2, 3, 4, and 5, were taken by the officers of the customs for the port of Philadelphia from cargoes imported into that city from the West Indies, in June or July, 1843, in compliance with the circular of the Secretary of the Treasury of 12th May, 1843. They had remained since that time in loosely stopped bottles, which stood in a dry place. That water had evaporated from them to a considerable extent, is shown by the fact that their specific gravities exceed those determined in July, 1843, by Messrs. Booth and Boyé for specimens just imported. This also renders my results, as given in the last table, nearly accordant with those of Biot and Soubeiran. What had been the effects of atmospheric fluctuations of temperature in causing fermentation during the year which has elapsed since the molasses was imported it is impossible to conjecture. When No. 2 was removed to a room heated by a stove, and allowed to stand on a shelf for several days, fermentation commenced, and the carbonic acid forced the cork from the bottle. On removing it to a colder room, this fermentation ceased. In it there was also a deposit of solid sugar, which constituted one-sixth by volume of the whole. In taste, it was slightly acid. Of No. 1, the taste was a pure sweet, very mild and rich; it contained no deposit; it is the same as No. 13 of the analyses of Messrs. Booth and Boyé. No. 3 contained no deposit, and was very acid to the taste. No. 4 likewise contained no deposit, and was very acid in taste. In No. 5 there was a deposit of one-fifteenth of the whole volume; its taste, at first purely sweet, acquired an acid flavor in the mouth.

18. I shall now apply to the analysis of these specimens of molasses the formulæ and process of inversion by acids of M. Biot. To this end, I employ the solutions of article 16, and hydrochloric acid of the specific gravity of 1.18, in volumes which I calculate from their weights and densities, by means of the well-known formula $w = d v$. Biot measures these volumes directly, by means of the tubes of M. Gay Lussac. The use of the balance is more exact. I mixed them in quantities which weighed, in grains :

	No. 2.	No. 3.	No. 4.	No. 5.	Density.
Solution -	219	281.9	218	299.3	1.1056
Acid -	41.5	59.2	36.1	49.8	1.18

The logarithmic calculations are as follows: Let $W = D V$ be the equation of volume for the saccharine solution, and $w = d v$ the corresponding equation for the acid; in which W and w are the weights of the table, D and d the densities, and V, v the unknown volumes to be calculated.

Then, for No. 2, we have

log. W	2.3404441	log. w	1.6180481
log. D	0.0435980	log. d	0.0718820
<hr/>			
log. V	2.2968461	log. v =	1.5461660
∴ V =	198.0825;	∴ v =	35.1695;
	V + v = 233.2520.		

For No. 3, we obtain

log. W	2.4500951	log. w	1.7723217
log. D	0.0435980	log. d	0.0718820
<hr/>			
log. V	2.4064971	log. v	1.7004397
∴ V =	254.9741;	∴ v =	50.1695;
	V + v = 305.1436.		

And for No. 4,

log. W	2.3384564	log. w	1.5575072
log. D	0.0435980	log. d	0.0718820
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log. V	2.2948584	log. v	1.4856252
∴ V =	197.17804;	∴ v =	30.5932.
	V + v = 227.77124.		

Lastly, for No. 5, we have

log. W	2.4761067	log. w	1.6972293
log. D	0.0435980	log. d	0.0718820
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log. V	2.4325087	log. v	1.6253473
∴ V =	270.71275;	∴ v =	42.233;
	V + v = 312.94575.		

From these volumes we compute the *ratio of dilution*, which is equal to $\frac{V}{V+v}$, and is the coefficient by which we must multiply the observed angles of the violet ray of art. 16, to reduce them to the proper state of dilution. I give the calculations by means of logarithms.

For No. 2,

log. V	2.2968461	log. (violet)	1.4114792
(log. V + v)	2.3678254		1.9290207
<hr/>			
= log.	1.9290207	log. a'	1.3405000
	0.8492.	∴ a' =	21°.9028.

For No. 3,

log. V	2.4064971	log. (violet)	1.3617278
log. (V + v)	2.4845042		1.9219929
<hr/>			
= log.	1.9219929	log. a'	1.2837207
	0.8355871.	∴ a' =	19°.2185.

For No. 4,

og. V	2.2948584	log. (violet)	1.3891661
log. (V + v)	2.3574984		1.9373600

	1.9373600	log. α'	1.3265261
= log.	0.86569	$\therefore \alpha' =$	21°.2093.

For No. 5,

log. V	2.4325087	log. (violet)	1.4494784
log. (V + v)	2.4954855		1.9370232

	1.9370232	log. α'	1.3865016
= log.	0.865014	$\therefore \alpha' =$	24°.35.

19. Having obtained the values of α' , the angle of deviation reduced to the same state of dilution as the acidulated mixture, and as it would have been observed by adding water alone, we next proceed to determine α'' the angle of deviation of the violet ray for the acid solutions. This is done by direct observation. On account of the color developed by the action of the acid upon the saccharine solution, I was compelled to use the method of minimum intensity and mean observations of angles of disappearance and reappearance of the image, except for No. 2, to which the acid had given only a slight yellowish tinge, which did not enfeeble the light sufficiently to obscure the violet ray.

The readings for No. 2 were 12° to the left, and then again 12°.25, of which 12°, 125 = α'' is the mean.

No. and color af- ter inver- sion.	No. 3. Orange.				No. 4. Orange.			No. 5. Orange.		
	Azi- muths.	Disap- pearance. <i>m.</i>	Reap- pearance. <i>n.</i>	Sum of (<i>m</i> + <i>n</i> .)	Disap- pearance. <i>m.</i>	Reap- pearance. <i>n.</i>	Sum of (<i>m</i> + <i>n</i> .)	Disap- pearance. <i>m.</i>	Reap- pearance. <i>n.</i>	Sum of (<i>m</i> + <i>n</i> .)
		— 4.	— 16.	20.	— 3.5	— 17.	20.5	— 5.5	— 12.5	18.
		7.	13.75	20.75	6.	19.	25.	6.5	12.5	19.
		2.5	15.5	18.	7.	15.5	22.5	6.25	12.25	18.5
		4.25	14.5	18.75	6.5	16.5	23.	8.5	15.5	24.
		5.5	15.5	21.	6.5	15.5	22.	7.5	16.	23.5
$\alpha'' =$	Mean, — 9°.85.				Mean, — 11°.3.			Mean, — 10°.3.		

20. To obtain r'' the ratio of inversion, we divide α'' by α' for the four mixtures; this calculation is as follows:

For No. 2,		For No. 3,	
log. α''	1.0836817	log. α''	0.9934362
log. α'	1.3405000	log. α'	1.2837207
log. r''	1.7431817	log. r''	1.7097155
$\therefore r'' =$	0.5536.	$\therefore r'' =$	0.5125.

For No. 4,		For No. 5,	
log. α''	1.0530784	log. α''	1.0128372
log. α'	1.3265261	log. α'	1.3865016
<hr/>		<hr/>	
log. r''	1.7265523	log. r''	1.6263356
$\therefore r'' =$	0.5128.	$\therefore r'' =$	0.423.

21. Now, by equation (5) of art. 11, it appears that

$$S = \frac{1+r''}{1+r'} \alpha'; \text{ and } D = \alpha' - S.$$

That in these formulas each quantity might be obtained from my own observations, independently of those of others, I determined, by experiment upon a solution of pure cane sugar directly and by inversion, for r' , the value 0.376, a result which differs from that of M. Biot, 0.38, only by 0.004, but by which quantity nearly my experiments were probably in error; for, as they were instituted only to confirm or disprove the coefficient of M. Biot, they were performed hastily, and without that extreme care which should always be bestowed on the determination of the constants of physical phenomena. Sufficient time, also, was not allowed to permit the inverted deviation to obtain its maximum. I shall therefore adopt the value 0.38 as the most probable coefficient.

The calculations for S and D, are :

For No. 2,		For No. 3,	
log. $1 + r''$	0.1913392	log. $1 + r''$	0.1796954
log. α'	1.3405000	log. α'	1.2837207
arith. co. log. $1 + r'$	9.8601209	log. $1 + r'$ arith. co.	9.8601209
<hr/>		<hr/>	
$\therefore S =$	1.3919601	$\therefore S =$	1.3235370
$\alpha' - S = D = -$	24°.6581;	$\therefore D = -$	21°.064;
	2°.7553.		1°.8455.

For No. 4,		For No. 5,	
log. $1 + r''$	0.1797815	log. $1 + r''$	0.1532049
log. α'	1.3265261	log. α'	1.3865016
log. $1 + r'$ arith. co.	9.8601209	log. $1 + r'$	9.8601209
<hr/>		<hr/>	
$\therefore S =$	1.3664285	$\therefore S =$	1.3998274
$D = -$	23°.2502;	$\therefore D = -$	25°.109;
	2°.0409.		0.759.

Hence the angles of deviation α' are caused by a quantity of cane sugar, which, for the state of dilution $\frac{V}{V+v}$ and the normal length 234 millim., produces a rotation equal to S, together with other active substances having a combined rotation of D to the left, but which may and probably does consist of a mixture of different uninvertible sugars, polarizing in opposite directions.

22. From the values of S of the last article, I proceed to calculate the per centage of cane sugar in the specimens of molasses. It will greatly simplify the calculations if we restore S to its value, before dilution, in the solutions of normal density. To this end, we must divide by the ratios of dilution of article 18; denoting these ratios by n , we have by equation (6) of article 11,

$$\alpha = \frac{S}{n l d e x};$$

In which l and d are of the normal values, and e is the proportion of molasses in the solution. From the densities given in the first table of article 15, I calculate for e the values, for Nos. 2 and 5, 43.08 per cent., and 30.43 per cent. for Nos. 3 and 4.

Now for 25 per cent. solutions of pure cane sugar, S is equal to 42° , by article 17; therefore,

$$\alpha = \frac{42}{25 l d} = \frac{S}{n l d e x} \therefore \frac{42}{25} = 1.68 = \frac{S}{n e x};$$

$$\text{And, finally, } x = \frac{1.68 n e}{S}.$$

The calculations by logarithms are therefore :

For No. 2,		For No. 3,	
log. 1.68	0.2253093	log. 1.68	0.2253093
log. n	1.9290207	log. n	1.9219929
log. e	1.6342757	log. e	1.4833020
log. S arith. co.	8.6080399	log S arith. co.	8.6764630
	<hr/>		<hr/>
	0.3966456		0.3070672
$\therefore x =$	24.925.	$\therefore x =$	20.28.

For No. 4,		For No. 5,	
log. 1.68	0.2253093	log. 1.68	0.2253093
log. n	1.9373600	log. n	1.9370232
log. e	1.4833020	log. e	1.6342757
log. S arith. co.	8.6335715	log. S arith. co.	8.6001726
	<hr/>		<hr/>
	0.2795428		0.3967808
$\therefore x =$	19.035.	$\therefore x =$	24.933.

These values of x express the quantities of crystallizable cane sugar in the normal solutions, which contain, respectively, 43.08 per cent. of molasses for Nos. 2 and 5, and 30.43 per cent. for Nos. 3 and 4; by proportion, therefore, we obtain the quantities of cane sugar in 100 of the molasses.

The logarithmic calculations, are :

For No. 2,		For No. 3,	
log. 100 x	3.3966456	log. 100 x	3.3070672
log. e	1.6342757	log. e	1.4833020
	1.7623699		1.8237652
∴ 57.86 = cane sugar.		∴ 66.64 = cane sugar.	

For No. 4,		For No. 5,	
log. 100 x	3.2795428	log. 100 x	3.3967808
log. e	1.4833020	log. e	1.6342757
	1.7962408		1.7625051
∴ 62.55 = cane sugar.		∴ 57.88 = cane sugar.	

Assuming, therefore, the correctness of the determinations of the quantity of water by the hydrometer of Greiner, as given in the first table of article 15, we have, as the composition of each specimen of molasses :

Molasses	No. 2.	No. 3.	No. 4.	No. 5.
Specific gravity	1.3953	1.3717	1.3609	1.4012
Cane sugar	57.86	66.64	62.55	57.88
Liquid sugar and organic matter	20.10	8.46	6.95	21.42
Water	22.04	24.90	30.50	21.70
Total	100.00	100.00	100.00	100.00

The specific gravities are those given in the first table of article 11, determined by the balance.

General practical remarks upon molasses and other saccharine substances.

23. At first sight, it would appear that the results given in the last table, article 22, differ too widely from other analyses to be correct. I would therefore remark, that they are based upon data carefully observed, and depend upon methods and calculations which are apparently free from error, and liable to no objection. And although both Biot and Soubeiran have given 40 per cent. as the proportion of cane sugar in sugar-house molasses, while Ventske estimated it at 60 per cent., it should be borne in mind that West India molasses is a very different article from the molasses of sugar refiners. The first results from an imperfect extraction of brown sugar, performed upon the plantations usually in great haste. It is the mother liquor of the first crystallization. The second has undergone two successive evaporations and crystallizations: the first, to obtain the loaf and lump sugar; and the second, for the bastard. It should therefore contain less of cane sugar. Besides, impurities, which exist in considerable quantity in foreign molasses, and which, by impeding its crystallization, greatly increase the per cent. of cane sugar, are not contained in the mo-

lasses of the refiner, made from the best raw or clayed sugar. If we compare West India molasses with the drippings from the loaves of refined sugar, (a fairer comparison,) then my analyses will appear in deficiency, instead of being in excess; for M. Biot found a specimen of such drippings to contain 70 per cent. of cane sugar. It may also be affirmed, for reasons which I will presently state, that, unless the solubility of cane sugar is greatly impaired by the presence of foreign substances, good molasses must contain at least 60 per cent. when first manufactured. Though Ventzke gives 60 per cent. for the proportion of cane sugar in sugar-house molasses, I am strongly persuaded that any analyses made by his method, whether the angles of deviation be exactly determined or not, possess no title to credit; for I concur with Hochstetter* in believing that Ventzke's experiment, from which he inferred that liquid cane sugar, or molasses sugar, possesses no rotary power, serves only to show that prolonged boiling may produce a neutral mixture of materials rotating equally in opposite directions. And even should fresh sugar-house molasses be converted, by boiling, into molecularly inactive liquid sugar, the negative values I have obtained for D, show that West India molasses contains left polarizing liquid sugar, which must affect determinations by Ventzke's method, by neutralizing the action of a portion of the cane sugar, and rendering the per cent. obtained deficient to an amount corresponding to a deviation equal to D to the right. Nor do I know any method of determining the relative quantities of cane sugar, and left polarizing sugar, except that of inversion by acids. That left polarizing sugar exists in West India molasses, follows from the fact that fermentation takes place; which, as already stated, occurred in No. 2, when removed to a warmer room, and forced the cork out of the bottle by the carbonic acid evolved.

24. The report of Messrs. Booth and Boyé to the collector of the port of Philadelphia (hereto annexed, and marked A) sets forth a remarkable and important fact, which, if the value of molasses depends upon the quantity of cane sugar it contains, renders the mode of levying duty by weight, as established by the present tariff, entirely in error. The fact to which I allude is, that molasses contains more crystallizable cane sugar, and less of mucilaginous or liquid sugar, in proportion as a given bulk of it weighs less. And this fact is confirmed by my own analyses, as given in the table at the end of article 22, obtained by the method of Biot, by inversion with acids; for it there appears that Nos. 2 and 5, which possess the greatest specific gravity, contain the least amount of cane sugar, and the largest proportion of foreign vegetable matter; while the lighter specimens, Nos. 3 and 4, contain very little foreign matter, and over 60 per cent. of crystallizable sugar.

25. However different the quantities of crystallizable or cane sugar given by Messrs. Booth and Boyé and by myself may at first appear, they are still in strict accordance; for, while the numbers of my table express the absolute or entire quantity of cane sugar in 100 parts by weight of molasses, the fourth horizontal column of the table of Messrs. Booth and Boyé gives only that proportion of the whole amount of cane sugar

* See Journal für Praktische Chemie, vol. 27; also, Franklin Institute Journal, 1843.

which crystallizes out of a saturated mother liquor, still retaining probably 66 per cent. of its own weight of cane sugar in solution. The Matanzas sirup (No. 15) was used as a standard of comparison, and the 43.65 per cent. of cane sugar of the fourth horizontal column is the relative quantity which will crystallize out of it as a mother liquor. From which result, Messrs. Booth and Boyé calculate the other numbers of that column, by proportion, from the absolute quantities obtained, which are not given in the table of their report. Now, a saturated solution at 212° Fahrenheit will contain about 80 per cent. of cane sugar; and of this 80 per cent., 50 will crystallize. A very simple proportion gives, therefore, 64 per cent. as the absolute amount corresponding to a yield of 40, by direct crystallization.

26. The fact I have just stated—that a pure solution containing 80 per cent. will yield but 50 to crystallization—is one of great interest and importance to planters, to refiners, and to the Government. It precludes all possibility of greatly increasing the yield by the first jet of raw sugar from the evaporating pan. It shows that improvements are rather to be made in working the second products; calls the attention of the planter to the molasses, as a material rich in its content of crystallizable sugar; and claims for the bastard and sirups the thought and skill of the refiner; while it also serves to determine what amount of drawback should be allowed on foreign sugar refined for exportation in the United States, furnishing, as it does, the knowledge which is requisite to decide the proportion of the raw material for which the duty should be refunded. It certainly greatly concerns the planter to know that it is impossible for him to obtain, without elevating the temperature beyond 212° Fahrenheit, and running the risk of caramelizing a portion of his sugar, more than 50 per cent. of the weight of the solution in good crystalline sugar. Supposing him to employ steam to heat his pans, then will 50 per cent. be the maximum product of the first jet; but the molasses will still contain 66 per cent. of cane sugar, of which 40 per cent. of good quality may yet be extracted. But in these remarks I make no allowance for the action of fermentation, acids, alkalies, salts, or other foreign substances, in preventing crystallization. That this action is powerful, is a well-known and established fact; yet the nature of the foreign substances in the expressed cane juice, and their proper management, has not yet been investigated with sufficient knowledge and skill.

A series of exact chemical researches, having for their object the determination of the substances, whether vegetable or mineral, composing the cane, and with a view to furnish methods of preventing their injurious effects, could not fail to be of great value. On this subject, much remains to be done; and to the planters of the United States, who have to contend with all the disadvantages of a more northern climate, against the competition of their more favored island neighbors, would such knowledge be particularly valuable. In illustration, I am told that there is often contained in Louisiana cane juice a large quantity of a substance like jelly. It prevents the proper defecation by lime, and will even clog the channel which conducts the juice from the mill, if lumps of chalk or lime be placed therein; it also precludes the use of bone black. Now, it does not appear to be either albumen or pectine; yet it interferes greatly with the manufacture of sugar, and therefore to understand its nature is of great importance.

By the researches of M. Hervy, it appears to be established that cane sugar is a primary secretion of the plant, and that it does not mature, like the sugar of fruit, from pulpy matter, but is contained alike in the old and new knots; in both of which the same simple structure appears; microscopic observation showing no difference for the different stages of vegetation; the same tubes, bundles of fibres, &c., appearing in all. In fruits, however, M. Frémy has shown that the cellules change from day to day. As they approach maturity, their thick walls, which at first are almost opaque, grow transparent, swell up and burst, discharging their acid contents. The action of this acid upon the ligneous matter may convert it into sugar, as starch and woody fibre are changed into a species of sugar by dilute sulphuric acid. Hence the reason that grape sugar may be produced artificially, while cane sugar appears beyond our power of manufacture. Now, it follows from this fact, and the direct experiments of M. Hervy, that crystallizable cane sugar is the only saccharine matter in the cane,* and that all the molasses sugar, grape sugar, &c., contained in molasses, are results of decomposition of cane sugar by imperfect management. Certainly, then, too much importance cannot be attached by the planter to a knowledge of the causes, and their remedies, which produce this decomposition. When beets grow in land too highly manured, or containing soluble salts, their juice is very difficult to crystallize, and yields a large quantity of molasses. So canes, grown upon soils where timber has been recently burned, take up the soluble salts by their roots, which must act very injuriously. Common salt will form a compound with six times its weight of sugar, which refuses to crystallize, and remains in the mother liquor; so likewise alkaline carbonates, and other salts, operate to increase the quantity of molasses, and injure the quality of the sugar.

27. The assertion I have made, that a solution containing 80 per cent. at 212° Fahrenheit will permit 50 only to crystallize, is based upon the following facts and experiments. In nearly all the elementary works on chemistry, it is erroneously stated that sugar "dissolves in hot water to any extent." The error seems to be copied from book to book, without even a change of language. At my request, Mr. Hewston, an assistant in the laboratory of Messrs. Booth and Boyé, performed the following experiment: 120 grains of pure cane sugar were treated at 212° Fahrenheit, with 20 grains of water, for one hour, and left 36.4 grains undissolved. It is true, therefore, as M. Dubrunfaut has stated, that water at 212° will not take up more than five times its own weight of crystallizable sugar, of which it parts with three by crystallization on cooling. This fact is confirmed by M. Hervy, and also by Biot's determination of the cane sugar in the drippings from the moulds for loaves, 70 per cent., as well as by my own experiments. Hence a saturated solution at 212° contains, say 16.6 of water, and 83.4 of pure sugar; on cooling, it parts with 50 per cent. The mother liquor contains 16.6 of water, and 33.3 of sugar, or 100 parts consists of 66⅔ per cent. of cane sugar, and 33⅓ of water.

28. To show the relation of this fact to the question of drawback, suppose that a refiner should attempt to recrystallize a quantity of the purest loaf sugar, or, in other words, to refine it over again; now, if he should

* See Journal de Pharmacie, t. xxvii; Janv., 1841.

follow the more common practice of employing an open evaporating pan, it is necessary that he should so regulate the heat that it may not exceed 212° , if he would avoid burning his sugar. Of every 83 pounds of sugar dissolved, he can therefore only get back 50, or 3 for every 5; so that of 100 pounds he will obtain but 60, the rest remaining in the mother liquid, to be worked up into bastard and molasses. But the refiner does not employ, as we have supposed, pure white cane sugar; he uses a mixture of white and brown sugar; the latter particularly contains a large proportion of molasses, hygrometric water, and other impurities. He cannot therefore, for this reason, obtain as much as 60 per cent. Secondly, after the loaf has become solid, the refiner usually applies to it the process of claying; moist clay is placed upon the bottom of the inverted loaf, and the water percolating washes out the sirup, except from the apex of the cone, which is therefore removed, as well as the portion of the bottom impaired by the clay. The quantity dissolved by the water of claying forms a saturated sirup, containing twice the weight of its water in sugar. To allow 10 per cent. for loss by these several causes is, I think, a small allowance. Hence 50 per cent. would be a large yield for refining by the ordinary process. Nor would the yield be much, if any, greater by the use of the vacuum pan of Howard; for it is not true, as is generally supposed, that the quantity of refined sugar obtained by the vacuum pan is much larger than that of an open boiler. It is true that a sugar of far superior quality and great beauty is produced by the vacuum pan, but in quantity it does not differ much from the yield of the old method. From facts furnished to me by some of the most experienced and intelligent of the refiners of our country, I find that 26,000,000 of pounds of raw sugar, refined by the vacuum process, and without claying, gave the mean product of 55.38 per cent. of loaf sugar; 1,000,000, refined by the old method, yielded 53.57 per cent., of which about 40 only were loaf sugar, and 13.57 lump, or of inferior quality. By the use of the vacuum pan, a very rarified atmosphere of steam is substituted in place of the air, which doubtless prevents to a very great extent, if not entirely, the formation of formic acid, which exerts a most pernicious influence upon the color and crystallization of sugar, and which Hochstetter has shown to be the product of the action of the oxygen of the atmosphere upon the heated sirup. Formic acid is also doubtless produced in large quantity during the operation of claying; for the drops which trickle through expose a very large surface to the action of the air. By allowing them to fall into a vacuum, or into steam, a better bastard sugar might probably be manufactured. In steam, the oxygen is united with the hydrogen by a very powerful chemical affinity, while the atmospheric air seems to be a mere mechanical mixture of oxygen and nitrogen, so feeble is the chemical force, if there be any, between them. Hence many substances are far more readily oxidized at the expense of atmospheric air than of steam, and especially those of organic origin; and the one supports combustion, while the other extinguishes it.

29. It has been thought that extensive frauds are practised upon the revenue, by introducing sirup of cane, battery sirup, or saturated solutions of sugar, colored by the addition of a little caramel, and flavored with a portion of genuine molasses; that this fraudulent article is purchased by the sugar refiners, who subsequently export the sugar they obtain from it with allowance of drawback; that thus the Government is

robbed annually of thousands of dollars; and the sugar trade of our Southern States deprived of that protection which the tariff is calculated to afford. To what extent frauds of such a nature may have been perpetrated, I am unable to say; and upon this point I have little information besides that contained in the reports made by the collectors of the principal ports, in reply to the circular of the Secretary of the Treasury of May 12, 1843. I therefore beg leave to refer to those reports, and to other papers now on file in the Treasury Department, but which are all embodied in a communication, made to the Senate at the close of the last session. (See Sen. Doc. No. 12, 2d session 28th Cong.) From the knowledge I possess of the nature of the article usually sold as West India molasses, and from the high quality of the standard adopted by the Government as refined sugar entitled to drawback, I do not hesitate to say that such sugar cannot, in the present state of the art of sugar refining, possibly be made from molasses, or sirup adulterated with molasses. Those refiners who extract sugar from molasses manufacture only a brown sugar, which contains so much uncrystallizable or mucilaginous sugar as to render it wholly unfit for refining. That from molasses, which usually contains nearly 60 per cent. of crystallizable sugar, and from which 40 per cent. may be actually crystallized, leaving still 20 per cent. in the mother liquor, a refiner may and does extract say 35 per cent., realizing a sufficient profit, is certainly not surprising. And these are facts which are established by the analyses of Messrs. Booth and Boyé and myself; and by the information contained in the report, to the Secretary of the Treasury, of the collector of Philadelphia, made 10th August, 1843.

Whether this branch of industry, which is pursued only by a few individuals, and to an extent at present which is trifling in its influence upon the sugar trade, shall be checked before it attains sufficient growth to interfere considerably in the home market with the brown sugars of Louisiana, is a question which I should leave with those upon whom the Constitution confers the authority and devolves the duty to determine; with the remark, however, that, so long as planters furnish to the market molasses which, like the specimens Nos. 3 and 4 of my analysis, contains 60 per cent. of cane sugar, and but a very small relative proportion of foreign matter, it will be found profitable to extract 35 per cent., unless a high relative duty is levied upon molasses. And whether it may be well to increase the tariff upon molasses, or whether the Louisiana planter, who, in competition with the West India trade, has to contend with the disadvantages created by his northern climate, should not receive further protection, is a question which belongs to the legislative department of the Government. As a chemist, I, however, do not hesitate to say, that sirup may be so disguised as to render it extremely difficult, if not impossible, for even experienced sugar refiners to decide whether it be molasses or not. And I feel confident that I could readily compose a mixture which would deceive both the officers of the customs and refiners by their usual tests of sight, taste, and touch, and without rendering it difficult to obtain from it a sugar which would be of very good quality, but which might not yield an article that would be allowed at the custom-houses to receive the benefit of drawback. It will be observed, by reference to article 17, that No. 3 and No. 4 of my analyses, which contained the most sugar and least foreign matter, were strongly acid to the taste, and contained no deposit of solid matter. They were also lighter instead of being heavier than No. 2.

or No. 5 ; a fact confirmed by similar analyses of Messrs. Booth and Boyé, and the reason of which is clearly explained in their report hereto annexed. These acid specimens would certainly not have been suspected by custom-house officers generally to contain the largest amount of crystallizable sugar ; and, if weighed, the inferior gravity would be equally deceptive. From a very intelligent refiner, I have learned also that he has found molasses which has a sour taste to give the best yield. I regret that an accident happened to the solution of the molasses called No. 1, which destroyed my analysis ; for it contained a very large deposit of solid matter, and was also the only specimen analyzed by Messrs. Booth and Boyé of those I examined. Cane sugar may be mechanically mixed with molasses, and fraudulently imported as a deposit in the cask ; it would then increase the weight, and could be readily detected by a revenue officer. But it does not follow that molasses, containing even a very considerable deposit, is mixed with sugar ; for this deposit may, and often probably does, consist of organic matter, less soluble than sugar. Such was, perhaps, the case in No. 5, which contained less sugar than No. 3 or No. 4, but had deposited solid matter to the extent of one-fifteenth of its volume.

30. In conclusion, I would state that, by the methods I have described, sugars, sirups, molasses, and other saccharine substances, may be accurately analyzed and distinguished from each other. There is not, to my knowledge, in Organic Chemistry a test so delicate and decided as the copper test of Trommer, with the exception of that of iodine for starch ; and combined chemical and optical analyses seem to possess all requisite accuracy for practical purposes. Already has this beautiful discovery of Biot found its way into refineries ; and the house of MM. Say & Duméril, of Paris, have employed it with accuracy and profit. The highly intelligent and enterprising proprietors of the firm of J. S. Lovering & Co., of Philadelphia, have also availed themselves of this process ; and in their establishment may be seen practically illustrated, on a large scale, the advantages to be attained by the union of science and art. To put the question entirely at rest, however, of what constitutes molasses and what sirup, and how one may always be distinguished from the other, as well as to establish the facts by an increased number of examples, which the analyses of a few specimens only, as given by Messrs. Booth and Boyé and myself, tend to show, I deem it expedient that further researches should be made upon this subject, and that the extractive matter precipitated from molasses by the subacetate of lead, and the deposits in casks should be particularly examined. Analyses of cane juice, in its different stages of progress, sirup of cane, battery sirup, &c., should also be made, which can only be properly done before it has suffered change by fermentation or otherwise in its removal from the place of manufacture ; which analyses may serve incidentally to show whether the above-mentioned disadvantages of climate, which affect the planters of our country, may not, at least in part, be alleviated by increased knowledge of the composition and properties of the material upon which they operate, and consequent improved processes of manufacture ; and thus the Government may be put in possession of all the facts necessary to enlighten and illustrate its policy with reference to this subject ; frauds, by being rendered of ready detection, will be prevented, and their attempts finally abandoned ; and knowledge will be obtained which cannot fail to be of general interest and great importance to all concerned in

the manufacture of sugar, whether as planters or refiners. These analyses may be made at but little cost, and, through the instrumentality of the officers of the customs and co-operation of the Treasury Department, the several varieties of molasses imported may be procured, accompanied with information respecting their places of manufacture and the times and ports at which they were shipped.

On the drawback to be allowed on foreign sugars refined in the United States.

31. I have felt much perplexed to devise the proper means of furnishing the evidence called for by the second clause of the resolution of the House of Representatives of July 21st, 1842. Not that it is difficult to decide what amount of drawback should be paid, or to obtain accurate information upon which to base suitable action; but experiments on a small scale will not answer the question, what is the practical economical result of large operations, although they may, and they do, confirm the testimony of those engaged in refining sugar. Such researches as those I have mentioned on the solubility and crystallization of sugar have, apart from their immediate value, that also of enabling us to sit in judgment upon testimony offered by persons professing an acquaintance with this branch of industry, and whose professions may be, and sometimes are, rather the fruit of boastful ignorance than of accurate knowledge. I have been struck with the discordance of statements which have been made by individuals, whose characters are beyond impeachment, and who doubtless all believed what they represented. But many of them testify from hearsay; hence it is natural that the Government should have been greatly at a loss what to believe, or what decisions to consider just.

The present refiners themselves, who only can testify from knowledge, have been regarded as interested witnesses; and old refiners, who have retired from the business, when they make statements with regard to recent improvements, usually speak from conjecture, and often imagine the results to be far beyond the actual facts. If we would resort to books for information, we are equally liable to be misled; for those books are generally the productions of foreign authors, who speak for their own countries; and it is a fact, highly creditable to our countrymen, that American refined sugar, of superior quality, surpasses, in excellence and beauty, any that is made in Europe, and that it therefore commands a higher price in foreign markets. But refining may be considered a separation of the impurities from raw sugar; and if we would obtain a better article, we cannot therefore produce so much of it.

I have come to the conclusion, that whatever may be the confirmatory experiments we may try on a small scale, the desired information can only be satisfactorily reached by recourse to the principal establishments themselves. But it would neither be proper to demand, nor fit that the refiners should expose to the public, private affairs upon which their success as individuals may often depend. Our Government very properly protects the private interests of her citizens in the fruits of their mental labor by patent rights; but there are advantages that some manufacturers possess over their competitors, which can only be properly secured by keeping them secret; and it is certainly no want of liberality that persons should reap the fruits of their own experience, often bought at the expense of heavy losses of

capital. I make these remarks because the refiners have been blamed for their secrecy; but those who have visited manufacturing establishments are aware that sugar refiners are not singular in keeping their secrets. I have not found them more so than others, and a proper personal introduction has never failed to open even the most hidden mysteries to me, yet in confidence that I would not divulge private matters, to the disadvantage of those who extended to me facilities of accurate information. It is from knowledge thus obtained from refiners of high standing and intelligence, as well as from my own personal observations of their processes, that I give the following as the probable average yield of refining in the United States. Thirty per cent. of white sugar and seventy per cent. of brown (the average mixture) yield

By the vacuum process :

By the old process :

Refined	-	55.4	Loaf	-	40.
Bastard	-	22.9	Lump	-	13.6
Molasses	-	17.4	Bastard	-	19.6
Dirt and waste	-	4.3	Molasses	-	24.5
		<u>100.0</u>	Dirt and waste	-	2.3
		<u>100.0</u>			<u>100.0</u>

These are the mean results, not of a particular variety of raw sugar, nor for a single year, but of millions of pounds, and of refining with great intelligence and skill. I calculate from them the drawback to be allowed as follows :

Duty on 30 pounds white, at 4 cents	-	\$1.20.00
Duty on 70 pounds brown, at 2½ cents	-	1.75.00
		<u>2.95.00</u>

For the vacuum process :

Duty to be retained on 22.9 pounds		
bastard, or brown, at 2½ cents	-	\$0.57.25
17.4 pounds molasses, at 4½ mills	-	0.07.82
		<u>0.65.07</u>

Drawback 4.15 cents per pound on 55.4 refined	-	2.29.93
		<u>2.29.91</u>

Difference in favor of the revenue	-	0.00.02
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For the old process :

Amount of duty, as above		\$2.95.00
19.6 pounds, at 2½ cents	-	\$0.49.00
24.5 pounds, at 4½ mills	-	0.11.02
		<u>60.02</u>

Drawback 4.4 cents on 53.6 pounds	-	2.34.98
		<u>2.35.54</u>

Difference in favor of the refiner	-	0.00.86
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The mean, 4.27 cents, or $4\frac{1}{4}$ nearly, would therefore be the fair average drawback to be paid on refined sugar, under the present tariff.

Preliminary to the inquiry, what is the amount of drawback to be allowed on refined sugar, is the question: what is "*refined sugar*" itself? The present tariff act, section 14, enacts, that "there shall be allowed a drawback on foreign sugar refined in the United States, and exported therefrom, equal in amount to the duty paid on the foreign sugar from which it shall be manufactured, to be ascertained by such regulations as shall be prescribed by the Secretary of the Treasury, and no more." Now, the question, *what is refined sugar under the meaning of the laws of the United States?* is fortunately not open to difference of opinion, although various countries have adopted different definitions, in conformity with their respective policies. In Great Britain, for instance, refined sugar is considered to be the whole product, including even the darkest bastard; and this explains the fact, that the refiners of that country are required to export 67 per cent. when refining in bond. But by the decision of the Supreme Court in the case of *Barlow vs. the United States*, 7 Peters, 410, it is established, that "if, in a loose signification among refiners, sugars should sometimes be spoken of as being refined, without having undergone the further process of claying, or if the whole mass resulting from that process should sometimes indiscriminately acquire among them that appellation in a like loose signification, still, if among buyers and sellers generally, in the course of trade and business, the appellation '*refined sugars*' is exclusively limited to the products called lump and loaf sugar, and never includes bastard sugar, the acts of Congress ought to be construed in this restrictive sense. This was the doctrine of this court in the case of two hundred chests of tea, *Smith, claimant*, 9 Wheaton's Reports, 438, 439; and there is not the slightest inclination on the part of this court to retract it. Now, without minutely sifting the evidence in this case, we think that there is a decisive and unequivocal preponderance of evidence to establish that bastard sugar is not deemed in a commercial sense '*refined sugar*.' The appellation is *exclusively limited to such as have assumed at some time the form of white refined loaf or lump sugar*. This is established, not merely by the testimony of merchants and grocers, and persons in the custom-houses, but by the testimony of sugar refiners."

Hence, of the 53.6 per cent. of refined sugar obtained by the old process, I have not in my calculations discriminated between the 40 per cent. of loaf sugar and 13.6 of lump, but have treated it all alike as refined sugar entitled to drawback. And if, as I have been told, at some of the custom-houses, lump sugar, or refined sugar of inferior quality, is not allowed the benefit of drawback, it seems to me that it is in clear violation of the legal rights of the refiner, which entitle him to claim on "*refined sugar*," of *any* quality, drawback "equal in amount to the duty paid," "and no more." In compliance with the tariff act of 1842, the Secretary of the Treasury took steps to ascertain this "amount of duty paid;" and they are reported in Senate Document No. 12, second session twenty-eighth Congress. Unfortunately for the interest of the refiners, the testimony of persons was relied on who did not testify correctly, and some of them even from conjecture. The yield of the process of refining was assumed to be 75 per cent. of refined sugar, while 60 per cent. is the maximum of possibility, and the drawback was consequently fixed at three and a half cents per pound. Had it been correctly determined, (and that it was not,

is the fault of those who offered testimony in the case,) I am of opinion that it would have been of great advantage to the commerce of our country, particularly in the Italian trade; for I am informed that at present much of the sugar refined in Holland and England is imported into the United States, and subsequently exported in Italian vessels, with allowance of drawback, to Italy. This is done for the purpose of obtaining the benefit of the differential duties, which have been established in favor of American produce with a view to the extension of Italian enterprise and the cultivation of commercial relations with the United States. And it is owing to the policy adopted by England and Holland, of allowing not merely drawback, but *bounty*, on refined sugar, that notwithstanding the double freight and commission, and the 10 per cent. of duty retained by our Government, the British and Dutch refiners can and do indirectly enjoy, to the exclusion of our citizens, the benefit of regulations which were intended for them alone. I have now before me a letter on this subject from the consul of one of the Italian Governments for the city of New York, furnishing evidence of what I have just stated; and I have been told, by very intelligent refiners, that, even with the comparatively high prices of labor which American workmen do *and should always* receive, they can compete with the refiners of Holland and England in Italian markets, if our Government will merely return to them the full amount of duty paid; and that this should be done cannot be doubted, not only because it is but justice to the refiner, but also because it would give employment to a large number of workmen, and greatly serve the commerce of our country.

To put the question of drawback on refined sugars entirely at rest, technical investigations can be made at slight expense, in a manner which will, I think, furnish, at an early day, facts that may be published without injury to private persons or violation of confidence, and which will leave nothing to be desired with regard to their completeness or their authenticity.

SECTION II.

INTRODUCTION.

32. The arrangement I have adopted in this Section is, first, to develop the general theory of hydrometers, with a decimal system for the graduation of their scales; after which, particular instructions will be given for their construction, and the different instruments in use in the United States and in Europe will form so many instances to which the general principles established may be applied. I shall then discuss the present state of our knowledge upon the temperature of the maximum density of water, and apply to the most exact observations a method of calculation more rigid than seems to have been used, and by which I obtain a different result. Lastly, I shall describe the systems of "proofs" of distilled spirits, both of Europe and own country, and give the results of an experimental comparison of the principal hydrometers used for ascertaining the strength of spirits.

In the subsequent part of this report, I have not ascribed to M. Francœur alone the decimal system developed in it, for it is to Professor R. M. Patterson, director of the United States mint, who urged upon me the expediency of such a system, and who, at the same time, informed me of the admirable method of decimal weighing he has introduced into the United States mint, that I am indebted for the suggestions which caused me to adopt decimal graduation before I knew even of the existence of the memoir of M. Francœur. The idea of decimal division belongs indeed to the age. In the *Journ. de Physique* T. 94, p. 204, there is a paper by M. Delezennes, in which a system of four hundred divisions is discussed; the views it presents may be easily adapted to a centigrade system. Within a few days, I have received from Paris the valuable memoir of M. Francœur on centigrade hydrometers, from which I have made several extracts in this report. But I have endeavored to be just by citing authorities to which I have referred; and these have, when accessible, always been the originals; thus also furnishing, incidentally, references to those who may desire a more extended acquaintance with the subjects of this report.

It is greatly to be regretted, that a report made by Professor R. M. Patterson to the Treasury Department, in 1825, upon the subject of hydrometers, was destroyed when the former Treasury building was burnt, and that no copy of it can now be found.

On the theory of the hydrometer, and a decimal system for its graduation.

33. By the laws of hydrostatics, it is established that a body immersed in a fluid is buoyed or pressed upwards by a force exactly equal to the weight of the bulk of the fluid which it displaces. Hence, if the body float, the weight of the volume of liquid which would fill the space occupied by the portion immersed is exactly equal to the entire weight of the body itself. From this single fact, with beautiful simplicity, the whole theory of hydrometry readily flows.

For, let the floating body be a hydrometer, having the usual simple construction, represented in Fig. (4) of a graduated stem, a bulb and a counterpoise, or ballast, to preserve it in stable equilibrium when in a vertical position. Let p denote its weight, y the specific gravity or density of the liquid in which it floats, and x the volume of the quantity displaced; then will

$$p = xy \quad \dots \quad (8).$$

This equation, as p is essentially positive, will be at once recognised as that of the hyperbola referred to its asymptotes. We have therefore a very simple curve for our instrument, which enables us easily to deduce all its properties; and of which the abscissas represent volumes of liquid displaced, and the ordinates the corresponding densities. The consecutive abscissas are therefore the degrees of the graduated stem. If the co-ordinates are rectangular, then will the hyperbola be equilateral, and p will be the modulus of the corresponding system of logarithms; we shall therefore call p the *modulus* of the hydrometer.

If the constant weight, or modulus, p , be determined by a balance, then will equation (8) easily give the value of the specific gravity y , corresponding to any particular value of x , measured on the stem.

Now, as the differences of the ordinates of the hyperbola corresponding to consecutive abscissas are not equal, it follows that the spaces between the degrees of the stem to read equidifferent specific gravities must be unequal, and that the stem for this purpose cannot be graduated into equal divisions.

34. Whether or not, in the present highly advanced state of philosophical instrument making, it may be easy to graduate a line, so that the degrees shall be laid off accurately at distances corresponding to differences of the ordinates of a hyperbola, practical mechanics only can say. But I should suppose that, as the lengths of these differences may be easily calculated, the graduated micrometer screw of a dividing engine would accomplish the desired object. Geometrical methods are not wanting, and they are so evident that they will readily occur to one acquainted with the elements of conic sections, and need not be given here. But that a hydrometer may be convenient and useful in the arts, it need not, and perhaps it should not, read specific gravities; for these are usually expressed in decimal fractions; therefore, are recollected with difficulty, and liable to accidental mistakes. The manufacturer has no need of them in his processes; and it is, for instance, far simpler and more easy to remember, that an acid or sirup has the density of 20° Beaumé, than that its specific gravity is 1.166612, that of water being unity. Hence we find that in France, though Brisson brought forward simultaneously a hydrometer reading specific gravities, and succeeded in causing a violent opposition to the instrument of Beaumé, the latter has come into very general use; and not merely in France, but also in other countries of Europe, as well as in the West Indies and our own country. Certainly, therefore, the cause of this must lie in the advantages which in the instrument of Brisson were found wanting. The difficulty of construction, and consequent high price, were perhaps the chief reasons why an instrument based on rigid scientific principles, was superseded by one depending upon arbitrary and uncertain rules; but which was simple and easy in its construction and use, and being of comparatively low cost, was therefore economical. Hydrometers are furnished, of equal accuracy of workmanship and fitness for the same purpose, which vary in cost so much, that one is sold for fifty cents, and another for twenty-five dollars; they are often injured, and must then be replaced. Certainly, therefore, price is a matter of great moment, and simplicity in construction and employment is of essential importance.

35. Nor is it necessary, even in scientific researches, that the densities measured should be always expressed in specific gravities; for simplicity tends to accuracy, and whole degrees of a hydrometer are often better than fractional specific gravities. Yet, as Science belongs not exclusively to any country or nation, she should speak every where a common language; nor is any one at liberty to violate its grammar, if he would be understood. Hence a hydrometer scale may be arbitrary, but must be founded upon invariable data, and the degrees of that scale should be translated into corresponding specific gravities when it is desired that they may be intelligible to the world. In article 32 I have shown, that when the *modulus* p is known, and the degree x observed, for any liquid, then the specific gravity y is readily obtained from equation (8) by a very easy calculation. For the reasons above given, further discussion of hydrometers to read specific

gravities is here unnecessary, and the simple theory upon which their construction should be based being briefly exposed, the subject may properly be left to men of science and accomplished mechanics. We therefore resume the examination of hydrometers graduated into equal divisions.

36. In equation, (8,) suppose that y becomes equal to unity—a condition which will be fulfilled when the hydrometer is put into distilled water at the temperature of its maximum density—then will p be equal to x . *The modulus of a hydrometer is therefore equal to the volume of water at its maximum density which the hydrometer would displace.* There are obvious reasons why the temperature of maximum density is that which should be selected. At that point, a variation of temperature of five or six degrees of Fahrenheit would only cause a difference of 0.0001; nor is there any liability to change from the liquid to a solid state, as is the case at the freezing point, which may be rendered statical by immersion in melting ice.

37. As hydrometers are generally applied to two different classes of fluids—aqueous solutions, which are more valuable as they contain more of the substance dissolved and are more dense; and fluids lighter than water, such as alcohol, which, on the contrary, are stronger as they contain less of water, and become lighter—the degree which corresponds to p , the modulus, or which marks the normal density of water, is a zero point for hydrometers, prescribed by the nature of their applications, and therefore having nothing arbitrary or uncertain in its determination. For fluids heavier than water, the degrees would read downwards, and be negative; while, for fluids lighter than water, they would read upwards, and be positive. In either case, the degrees increase in proportion to the quantity of the substance which imparts value to the liquid. The zero point of a hydrometer might be assumed as that of its volume, or at the lower extremity, where x is equal to nothing; and, to avoid fractions, the modulus might be marked 100 on the stem; water would then be 100 instead of unity. To such a scale, the only important objection would probably be, that for fluids lighter than water the degrees would read inversely, instead of directly, as their commercial values; and this objection would be found a serious one in its application to the arts.

38. Assuming, therefore, that the modulus of a hydrometer, or its weight, establishes its proper zero point, we may proceed to show how the instrument can be graduated without introducing any thing capricious into its construction. As the equi-different values of x mark the divisions of the scale, and denote in equation (8) volumes displaced, the modulus or normal volume must contain a certain number, whole or fractional, of these divisions; which number is entirely arbitrary, for the variable x is subject only to the condition that its increments shall be equal, though they may be of any magnitude whatever. Accordingly, we find that one of the most general artifices adopted by instrument makers, to render the construction of a particular hydrometer a secret, and a monopoly to their own profit, has consisted in the capricious selection of a value for the increments of x , or the divisions of the scale. Add to this another artifice, that of an arbitrary change of the zero point, and we have the explanation of the fact that hydrometers have been multiplied until almost every city of any consequence

has produced its hydrometer, known only by the name of its maker, and possessing no peculiar advantages over others, from which it differs in no material respect. I have endeavored to inform myself of all the hydrometers in extensive use, either in Europe or in our own country, but am still constantly hearing of another, different from the rest only in its particular arbitrary construction. And they may be multiplied indefinitely. If a commercial mystery were not made of the data upon which any one of these instruments is constructed, its indications would be easily intelligible by being convertible into specific gravities; and if broken, it could readily be replaced by any good workman, which cannot be done if the basis of the instrument be kept a secret. Now, all this confusion may and should be done away with, at least in as far as the public service of our country is concerned, by the establishment by law of a system of hydrometry founded upon published and invariable data, and as free from an arbitrary nature as it is practicable for it to be.

It has been shown that some particular volume must be given to the differences of x ; or, in other words, the modulus must be divided arbitrarily, but we cannot be at a loss to determine what that number ought to be; for the decimal system of notation has become incorporated with all our ideas of number, until they seem almost inseparable from each other. To those who have become accustomed to our beautiful decimal coinage, and have often contrasted it with the complex system of guineas, pounds, shillings, and pence, the decimal division of a scale needs no argument to commend it to their adoption. In trade, articles bought and sold are usually divided, if at all, into halves, or quarters; thus the yard is subdivided rather into halves, quarters, and eighths, than into feet and inches. For convenience, therefore, the fractional parts of the unit of value, the dollar, are halves and quarters; but this does not impair either the utility or beauty of the method of counting by dollars and cents. In strict analogy, therefore, with our simple coinage, the hydrometer may be decimally divided, each degree being equal to the hundredth part of the volume of the modulus, or bulk of distilled water at its maximum density displaced by the floating instrument. And these degrees may be again subdivided decimally into tenths, hundredths, etc., so that any desired degree of sensibility may be given to a hydrometer belonging to this system.

39. It is evident, from equation (8), that so long as the weight p of a hydrometer remains constant, the value of x , corresponding to any given value of y , will not vary. Suppose that by a blow the bulb of a metallic hydrometer becomes indented, and its volume consequently diminished, then will it sink deeper to an extent equal in volume to that of the indentation, and this quantity becomes therefore a constant correction of the zero point, to be applied subtractively for fluids lighter than water, or to positive readings, and additively for fluids heavier than water, or to negative readings. But the differences upon the scale will be exact.

40. For any two hydrometers of different weights we have

$$p = xy; \quad p' = x'y,$$

when they are plunged into the same fluid, of which y denotes the density; hence,

$$\frac{p}{p'} = \frac{x}{x'};$$

or the degrees are to each other in the constant ratio of their respective moduli. And as this is true for any values of y , x , and x' , which correspond to each other, it is true for all; or, in the decimal system, when

$$x = n \frac{p}{100}, \text{ then } x' = n \frac{p'}{100}.$$

It is therefore evident that any two hydrometers of the decimal system, however different in their respective weights and sizes, will read the same number of degrees, when plunged into the same liquid. And if the sections or diameters of their stems are of the same magnitude, then will the lengths of the degrees, or divisions on the stem, be proportional to the weights of the instruments. Hence it follows, that in Dycas's and Sikes's hydrometers, to which weights are added, the degrees on the graduated stems belong to systems of very different sensibility for each successive weight; or that each weight constitutes in fact a distinct hydrometer of a series, a very complicated arrangement.

41. For the same hydrometer, suppose that y varies geometrically, or that it is immersed in liquids of different specific gravity. When

$$y' = 2 y, \text{ then will } x' = \frac{x}{2}.$$

Hence, in hydrometers of the decimal system, 5° below zero will correspond to a specific gravity of 2,000, water being unity. For a specific gravity 1.500,

$$\text{as } y' = \frac{3}{2} y, \text{ and } x' = \frac{2}{3} x;$$

a hydrometer of the decimal system would read $-33\frac{1}{3}^\circ$, while 25° corresponds to a specific gravity of 1.3333. Above zero, if

$$x' = 2 x, \text{ } y' = \frac{y}{2};$$

then, in the decimal system, $+100^\circ$ will correspond to a specific gravity of 0.5000. Hence, the hundredth degree of the decimal hydrometer will slightly, but sufficiently, exceed the point requisite to show the specific gravities of sulphuric ether, caoutchoucine, and the lightest known liquids. And all liquids lighter than water, at present known to chemists, will have their densities comprised between zero and $+100$; while those heavier than water will be indicated by the negative degrees from zero to 100° below. The simple law, that the degrees of hydrometers vary inversely as the specific gravities, gives rise, as we have seen above, to the fact that specific gravities of $\frac{1}{2}$, $\frac{4}{3}$, $\frac{3}{2}$, 2 etc., correspond to indications of 100° above zero, and 25° , $33\frac{1}{3}^\circ$, 50° , etc., below zero. Nothing therefore seems wanting with respect to simplicity in this system.

42. We have hitherto supposed that the weight of the hydrometer is sustained only by the liquid in which it floats; but the air also aids in its support, by the buoyancy it exerts upon the stem. If we denote by a the relative density of air to that of water, and by v the total volume of the hydrometer, then will $v - x'$ be the volume of air occupied by its stem. If we had experimented in vacuo, for the absolute weight p we should have found

$$p = x y.$$

But in air we have

$$p = x' y + a (v - x');$$

$$(x - x') = \frac{a}{y} (v - x') \quad \dots \dots (9);$$

which is therefore the correction to be added to x' , the degree observed in air to reduce it to x , the degree for experiments in vacuo. The error committed by disregarding this correction would evidently be least when the density of the liquid or y is greatest. And if y be constant, then will the error vary with a ; which depends upon the pressure and temperature of the atmosphere, as indicated by the barometer and thermometer; so that

$$a = a' \frac{b}{(1 + k t)}$$

will be the value of a in terms of the normal density a' ; b being the coefficient of pressure, t the degrees of the thermometer observed, and k the coefficient of the atmospheric dilatation. At 60° Fahrenheit and 30 inches of the barometer, the specific gravity of air appears, by the experiments of MM. Biot and Arago, to be 0.001220, water being unity; if we take the cubic inch of water equal to 252.525 grains, then, for a cubic inch of air, we have 0.30808 grains. If the portion of the stem above the surface of the liquid ($v - x'$) be one cubic inch in volume, 0.30808 is therefore the quantity, which, when divided by the density y , would give the correction to be applied, provided that our experiments are made at 30 inches of pressure and 60° Fahr. Suppose that the liquid is water, or y equal to unity, and that the hydrometer weighs 500 grains, then will 5 grains correspond to one division of the scale, and 0.06 will be the error committed by omitting to take into consideration the influence of the atmosphere. Hence, as y varies within narrow limits for all known liquids, except mercury, say from 0.65 to 2.0, we conclude that an allowance for atmospheric pressure need not be made in the ordinary use of hydrometers; and is only called for in nice scientific investigations. Still less is it, therefore, requisite that we should take into account the effects of the small barometrical and thermometrical oscillations of the atmosphere on either side of its mean or normal state.

43. We have likewise assumed that observations of the hydrometer are made at the temperature of the maximum density of water, at which the volume of water displaced x becomes equal to p , and y is unity. At any

other temperature, the volume of water being greater, y will be less than unity, and x will become greater than p ; or, in other words, the hydrometer will sink. But, as heat generally expands, and loss of heat contracts bodies, whether solid, liquid, or gaseous, the hydrometer itself will undergo a change of volume whenever the temperature of the liquid varies. While, therefore, the dilatation of the liquid tends to sink the hydrometer, its own dilatation causes it to rise; which action is reversed in each for contraction. Hence the influence of temperature tends to work out its own compensation. If the ratio of dilatation were the same, both for the hydrometer and the liquid in which it swims, then would this compensation be perfect; but, as they generally vary very considerably, there will be found an uncompensated equation of dilatation of appreciable magnitude, to be applied to observations made at other temperatures than that of the maximum density of water. And this equation will vary with the coefficient of dilatation of each particular liquid. Hence it becomes important, and even indispensable, that tables of dilatation should be obtained, by exact researches, for the different liquids to which a hydrometer is applied. From these, as data, tables of correction, having the temperature observed for their argument, should be calculated; or a simple approximate arithmetical rule for corrections may be given, if one can be deduced; or a mechanical scale, with a sliding rule, may be used, to avoid all calculation or use of tables; or, lastly, the thermometer employed may be graduated to read directly, instead of its usual degrees, the corrections to be applied to indications of the hydrometer. The coefficient of dilatation of the particular metal or kind of glass of which a hydrometer is made must also be determined with accuracy by nice experiments. If we consider the dilatation of the hydrometer apart from that of the liquid, then will it cause for each degree of temperature a particular increment of volume, and consequent change, principally of the zero point, which will be constant for different liquids.

To obtain the general law of corrections for temperature, let k be the coefficient of cubic dilatation for the liquid, and k' the corresponding coefficient of the hydrometer; let t also denote the temperature reckoned from that of maximum density as the origin of temperature; then will

$$y = y' (1 + k t) \quad (10).$$

$$p = x' y' (1 + k' t) \quad (11).$$

From which equation, if we put it under the form

$$p \frac{1}{1 + k' t} = x' y' \quad (12),$$

it appears that the hyperbola will no longer be equilateral, unless $k' = 0$; but that for all values of the coefficient of p less than unity, if we represent this coefficient by $\sin. u$, we shall have

$$p \sin. u = x' y' \quad (13),$$

which is the equation of a hyperbola, whose asymptotes form with each

other an angle equal to u , and of which $p \sin. u$ is the power. And for any observed indication, or degree x , the corresponding reduced value y' of the density, will be

$$y' = \sin. u \frac{p}{x'} \quad - \quad - \quad - \quad - \quad - \quad (14).$$

As the coefficient of dilatation for solids is always positive, $1 + k' t$ will be greater, and $\sin. u$ be therefore less than unity.

Hence, it follows that, for any particular temperature observed, the indications of the hydrometer and the corresponding specific gravities will be correctly represented by the abscissas and ordinates of a hyperbola referred to oblique asymptotes; and the ratio of unity to the dilatation of the hydrometer will be the sine of the angle formed by the asymptotes with each other; the power of the hyperbola being also the sine of this angle multiplied by the weight of the instrument.

44. Although, in applying to the decimal hydrometer of article 38 the general conclusions derived from equation (8,) where the origin of abscissas is the lower extremity of the instrument, it becomes necessary to introduce the formulæ of transformation of co-ordinates, which correspond to the zero point given by immersion in distilled water of maximum density, as a new origin of abscissas. Yet, as the values of y remain unaffected by this change, and as

$$x = a - x' = 100 - x',$$

is therefore the only formula of transformation to be introduced into the expressions to refer them to the new axes; it is more simple to omit the introduction of $a - x'$ into our algebraic expressions, and merely substitute $100 - x'$, or the arithmetical complement, in place of x , the abscissa, in the numerical value of a formula. This may be performed mentally, as exemplified in article 41 of this paper.

45. Various hydrometers, like that of Dycas, are adapted to liquids of very different specific gravities by the addition of weights; which could not be done otherwise, without making the stems of inconvenient length. It is therefore requisite to give the theory of such instruments, more especially as the mechanical construction of hydrometers belonging to the decimal system should be performed by varying their weights, and as by use of weights we may combine the advantage of a short stem with the simplicity and perfection of decimal graduation.

Suppose, therefore, that we mark the degree x , to which the hydrometer sinks in distilled water of maximum density, and that we add internally a known weight, which we shall denote by w ; then will this cause the hydrometer to sink to a degree marked x' , for which the additional quantity of water displaced is equal to w in weight, and $x' - x$ is its volume in degrees. To ascertain the value of $x' - x$, the weight p of the hydrometer must be accurately determined by the balance, and divided into any conventional number of degrees, which number is represented by n ; then shall we have, by proportion,

$$\frac{n^{\circ} w}{p} = (x' - x)^{\circ} \quad - \quad - \quad - \quad - \quad - \quad (15).$$

If, for example, we suppose the hydrometer to be of the decimal system, $n = 100$, and that it weighs 500 grains, then

$$w = 5 (x' - x).$$

If w be taken successively equal to 50, 100, 150, 200, etc., grains, $x' - x$ will become 10° , 20° , 30° , 40° , etc.; or, in other words, the additional portion of the stem which the given successive weights cause to be immersed must be graduated into the above corresponding equal divisions. If we subtract instead of adding weights, then will equation (15) still answer, by making $x' - x$ negative; so that

$$w = 5 (x - x')$$

for hydrometers of the decimal system.

46. Hydrometers of the decimal system may be constructed with weights, but as each weight gives a new modulus and a different length to the divisions of the scale, their stems must be prisms of as many sides and separate graduated scales as there are weights employed. These scales should read continuously, so that the degrees will constitute a single scale.

47. As the degrees of a hydrometer, to be readily observed, should not be less than one-twentieth of an inch in length, the stem of the decimal hydrometer would have the inconvenient length of seven and one-half inches, and the instrument be both extremely fragile and unstable in its vertical position for the lower degrees; there are therefore practical difficulties in the way of constructing and using such an instrument. But in its use it is rarely that it is needed by the same person to perform two different offices, for each employs it only for a particular liquid, as, for instance, the distiller for alcoholic liquors, the brewer for malt solutions, the tanner for those of bark, the manufacturing chemist for acids and salts, the sugar refiner for sirups, &c.; hence it is not only unnecessary, but inexpedient, that the scale of the instrument should extend beyond those degrees which are requisite for the particular purpose to which it is to be applied. And hydrometers may be made with equal facility and less expense of shorter stems, and of any desired degree of sensibility, the divisions of which shall be comprised between the limits of any given degrees of the decimal system, positive or negative, which will best adapt them to their use. Such hydrometers are infinitely preferable to a universal hydrometer; but that they should form parts of one general decimal system is very desirable.

48. The materials of which hydrometers are usually made are glass, silver, copper, brass, and German silver. The great economy of glass, its perfect cleanliness, resistance to corrosion, incapability of fraudulent change of form or weight, and facility of manufacture, are qualities possessed to the same extent by no other known substance. But its fragility prescribes limits to the sensibility of glass hydrometers, and renders metal often preferable. Still, glass instruments only should be used in trade, unless frauds can be otherwise prevented by appropriate legislation. The extent to which abuses are committed by dealers in alcoholic liquors is believed to be enormous; and so it may remain, unless some means be adopted to render them impracticable. The use of glass hydrometers, correctly constructed, and liable to inspection by legally appointed persons, would preclude all

sales of liquors; and certainly while governments, by standard weights and measures of length and capacity, prevent dishonesty in trade with respect to other articles, they should regard as worthy of their consideration, and of similar protective legislation, a branch of commerce in which the perpetration of crime seems to have become so common as to pass for superior sagacity. Metallic hydrometers may easily be rendered fraudulent; indentations, to which they are ever very liable by accident, operate in favor of the dealer against the purchaser; and in levying duty, they operate for the revenue against the importer. Unless such instruments are inspected, from time to time, no reliance is therefore to be placed upon them. I need not, and I should not, show how hydrometers are designedly rendered fraudulent, and made to operate for or against the purchaser, one for buying, another for selling. I will only add, that this is very easily done for any metallic hydrometer, but for glass instruments can be readily accomplished only by the makers or by practical chemists. Copper hydrometers, made by the recently discovered electrotype process, may possess advantages over all others of metal. I am told by Mr. Saxton, the distinguished philosophical instrument maker, now employed in the fabrication of the standard weights and measures of the United States, and whose skill is known better perhaps in Europe than in this his native country, that hydrometers could be made by the electrotype method, which would combine facility and superiority of workmanship with greater certainty in use. Their coefficients of dilatation he also thinks would be less variable than those of wrought metal; but upon this subject I beg leave to refer to Mr. Saxton himself, with the remark, however, that I deem it highly important that a series of nice experiments should be made, to determine the coefficient of dilatation and mechanical properties of electrotype copper, with a view to this application. Metallic hydrometers may and should be gilded by electro-gilding with gold or platinum, by which they will be rendered incapable of corrosion by liquids generally, and may perhaps be employed even for acids.

49. As the decimal system of hydrometers, to be of convenient adoption in place of the instruments now in use and by habit rendered familiar to those who employ them, should be comparable with them by even the most ignorant workmen, it would be advisable, and perhaps necessary, that not only tables of comparison should be constructed, but that the stems should be graduated on their different sides to read both the old and the new degrees. Thus, by daily use, the new and more simple decimal scale would become equally familiar, and the old scales would be abandoned without perceptible inconvenience. Besides, by selecting those instruments which appear to be of greatest accuracy of their particular sorts, they would, by comparison with the decimal system, be referred to perfectly rigid bases of construction as standards, and differences of whole degrees would no longer exist in the instruments employed and offered for sale by the trade. Thus an instrument, having on one side the decimal scale, should be graduated to read degrees Beaumé on the other; and this instrument, regarded simply as a Beaumé's *pèse-acide* or *pèse-esprit*, would possess the advantage over other hydrometers according to Beaumé, of being *always graduated correctly*, an advantage which certainly should recommend it to use.

There are hydrometers in use which read not specific gravities, nor divisions of an arbitrary scale, but per cent. of the substance dissolved which

confers value upon the solution; such are, for instance, the beautiful centesimal alcoholometer of M. Gay Lussac, and the *saccharometer* of brewers, which reads sometimes the number of pounds of malt extract or fermentible matter in a barrel, and sometimes the per cent. instead. And it is greatly to be desired that the use of such instruments should become more extended; a *pèse-sirop*, for example, might read per cent. of sugar in solution, instead of degrees Beaumé. For such instruments, the decimal system of hydrometry will furnish by its degrees fixed points of reference, or data of construction, which may be more readily determined than the corresponding specific gravities, to which they are therefore far preferable.

50. In conclusion, it appears from the preceding articles that the greatest disorder exists with reference to the hydrometers now in use; that they are arbitrarily and capriciously, and may be infinitely varied without material advantage, and simply for the commercial purpose of imposing the maker's name upon them; that they are not comparable, because each maker endeavors to keep secret the method of construction he employs, and which alone can render the indications intelligible; that therefore, if broken, they often cannot be readily replaced; that they are *generally* inaccurate, and often *fraudulently* employed; that they may very easily be rendered fraudulent, if accurate; that as the division of the scale of the hydrometer is arbitrary, it should be decimal; that this decimal scale should, as some liquid must be employed, be referred to water, distilled that it may be pure, and at its maximum density, because that density is practically stationary; that there should be a single uniform scale of 100 degrees for liquids lighter than water, and 100 degrees for liquids heavier than water; that glass hydrometers cannot readily be rendered fraudulent, except by their makers; that hydrometers of the decimal scale may be constructed of metal, with or without weights; that they are readily graduated by the use of weights; that by graduating hydrometers to read old established scales on one side of the stem, and degrees of the decimal scale on the other, excellent instruments of the old divisions will replace the inaccurate ones now in use, and even the most ignorant workmen will readily adopt and insensibly acquire the habit of using the simpler decimal hydrometer; that it is therefore highly desirable, and worthy of the Government of a country like our own, to regulate the use of hydrometers in commerce, and establish a uniform, exact, and invariable system, by authority of law, and that such a system is afforded in the decimal system proposed.

If the Government should see fit to adopt a decimal system of hydrometry, it will be requisite that standard instruments be constructed, both in glass and metal; and I shall therefore now give practical directions, which it would be necessary to observe in making such hydrometers. But from standard instruments others may be made by tradesmen with less trouble and at less expense, as thermometers are now graduated by comparison with a standard.

Method of manufacture to be observed by instrument makers, in the construction of standard decimal hydrometers.

51. We suppose the bulb and stem to have been fashioned, and the instrument ready to receive its counterpoise and graduated scale. Care should be taken that the instrument be constructed symmetrically about its axis, to

prevent its leaning when but slightly immersed. If it be intended for liquids lighter than water, add weight *internally* until when immersed in recently distilled water at the temperature of maximum density, 4° centigrade, or $39\frac{1}{2}^{\circ}$ Fahrenheit, it sinks to the bottom of the stem; the degree it marks will be the zero point of the hydrometer. If, however, the hydrometer be intended for fluids heavier than water, then must its counterpoise cause it to sink to the top of the stem in distilled water of 4° centigrade, as a zero point.

Weigh the hydrometer and its counterpoise accurately by means of a delicate balance, and it will greatly simplify the graduation if the hydrometer and counterpoise be made to weigh in grains one of the round numbers 100, 200, 300, 400, etc., which may easily be done; then divide this weight by 100, the quotient will be the number of grains which will sink the hydrometer one degree of its scale. If, for instance, the hydrometer weighs 500 grains, then will 5 grains be the weight to be added or subtracted to cause it to sink or rise one degree; 10 grains will give 2° ; 15 grains 3° ; 50 grains 10° ; and so on to 500 grains for 100° , or as far as the length of the stem will admit of the extension of its scale. These weights must be added to hydrometers *internally* or at the *top of the stem*, if they are to be used for liquids lighter than water, and subtracted from those designed for liquids heavier than water.

If the hydrometer be of glass, weights may easily be added or subtracted by leaving the stem open at the top before it is graduated. A finely graduated slip of paper, of *exactly the same weight* as that intended to receive the degrees of the scale, will serve to mark the depths to which different weights cause the hydrometer to be immersed. After these depths are determined, the weights being restored to that of the modulus, the scale is divided and fixed within the stem in its proper position, and the top is then hermetically sealed.

For metallic instruments, this may be accomplished by counterpoises, of different weights, but *precisely equal volumes*; or a hollow counterpoise may receive internally weights of different amount. It is necessary in all cases that the volume of the bulb and counterpoise should be constantly the same.

By attaching the hydrometer by means of a silk worm's fibre or a human hair to the arm of a delicate balance, weights of any desired value may be easily subtracted from it, with greater accuracy and convenience than by any other method.

If the stem of a hydrometer be very fine, the ratio of the capacity of the bulb to the stem will be very great, and the instrument will possess extreme sensibility.

In reading off the degrees, or marking the depths to which the instrument sinks, capillary attraction will cause an elevation of the liquid about the stem. This may be prevented by an extremely thin film of oil.

52. As degrees of the hydrometer are measured by equal volumes of water displaced, it is essential that the stem be of uniform diameter throughout, or that any want of such uniformity be corrected in the graduation. To ascertain whether it be regular, the method suggested by M. Francœur is very accurate and convenient; wrap a fine thread evenly and closely round the stem a certain number of times, say one hundred, at different places; the measure of the length of the thread required will give the

circumference, if divided by the number of its wrappings. If the diameter be found to differ but slightly, then may its variation be rendered practically inappreciable by graduating the stem in portions, as is done for thermometers the tubes of which vary slightly in their bore at different places.

53. To graduate a hydrometer of known weight, which shall be without the degrees between zero and any desired division of the decimal scale, let it be of such weight that it will sink entirely in water, if for a heavier liquid, or so that its bulb may not be wholly submerged, if for lighter liquids; then add or subtract weights for two successive divisions, as described in article 51, and graduate the interval between into the proper corresponding number of degrees or equal fractional parts. Such hydrometers are very generally employed in the arts; for the degrees near to zero, or that of water, are rarely of any use, and only increase the length of the stem inconveniently.

54. To construct hydrometers with weights, consider the instrument and additional weight as a new *modulus*, divide the sum by 100 for the weight corresponding to a degree, and graduate for such degrees a new scale on a different side of the stem. A single scale will not therefore serve for various weights. These weights cannot be immersed if of different size without producing changes of volume by the water they displace, thus affecting the position of the zero point; hence they should be added either internally or at the top of the stem; or the counterpoise may vary in weight, while its volume should be constant.

55. To construct cheap and sufficiently exact hydrometers for the trade, use two different liquids, corresponding to the desired divisions of the decimal scale, prepared by means of a standard hydrometer; and having examined the uniformity of the diameter of the stem, graduate the interval between the points to which they sink into the proper number of divisions.

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Description of the principal hydrometers now or formerly in use.

56. In this section I shall give an account only of those instruments which have been generally adopted, and therefore are best known in France, England, Germany, and our own country, reserving other and comparatively less familiar hydrometers to be discussed hereafter. The *pèse-acide* and *pèse-esprit* of Beaumé are so commonly found in the workshops of all the above-mentioned countries, that they deserve our first attention.

57. *Beaumé's hydrometers.*—For fluids lighter than water, Beaumé invented his *pèse-esprit* (*hydrometer for spirits*; *Brannteweinmesser*, Germ.) and for fluids heavier than water, a single instrument, called, with reference to its particular applications, by the different names of *pèse-acide*, *pèse-sel*, or *pèse-sirup*, (*acid, salt, or sirup measure*; and *Säuremesser*, *Salzspindel*, or *Zuckermesser*, Germ.) These instruments are entirely distinct, and form no part of a common system, for they are constructed on different bases. The degrees of one are not equal to those of the other; and the zero point, which is determined for the *pèse-esprit* by a solution containing

ten per cent. of common salt, corresponds in the *pèse-acide* to the density of pure water. Hence we shall treat of these instruments separately.

The *pèse-esprit* is constructed by immersion in a solution of common salt, containing, as already stated, ten per cent., to obtain the zero point; then by plunging it into water to determine another point, which Beaumé calls 10° ; the interval is graduated equally, and the scale extended by laying off, repeatedly, with a pair of dividers, the same interval upon the stem.

The zero point of the *pèse-acide* is given by the surface of the distilled water in which it floats. Immersion in a solution containing 15 per cent. of common salt fixes the point which is to be marked 15° upon the scale. And degrees beyond 15° are determined by the same process of extension employed for the *pèse-esprit*.

It might at first be supposed that the degrees of these instruments would constitute parts of a common scale; but the densities of two solutions of common salt containing, one 10, and the other 15 per cent., will not be such as to correspond to equal degrees 10° and 15° reckoned from water as a common origin; and, therefore, Beaumé's hydrometers belong to different scales.

It is a great and fundamental defect of these instruments, that their scales are constructed by the multiplication of a unit of length; for workmen generally commit an error in determining the fixed points, on account of the elevation of the liquid upon the stem by capillary attraction; and this error becomes multiplied by each successive repetition. Hence it is easy to perceive the reason why Beaumé's hydrometers, constructed by the same person, and with equal care, often differ whole degrees from each other, when plunged into the same liquid. This fault is the more important, as it affects principally those degrees which are most used. In hydrometers of the decimal system, discussed in the preceding sections of this report, the graduation is performed by the subdivision of a multiple; and, therefore, any error which unavoidably occurs in measuring the fixed points will be diminished in the ratio of the number of divisions of the interval between them, which certainly constitutes a great advantage, and renders accuracy of workmanship almost certain.

Another defect of the process of Beaumé for graduating hydrometers is, that common salt generally contains impurities; and to obtain it, therefore, perfectly pure, is impracticable, without a degree of chemical knowledge which instrument makers rarely possess. And even if pure salt be obtained, and the solutions be properly mixed, they are liable to evaporation, which will alter their proportions and density.

The uncertainty of the indications of these hydrometers is established by the fact that tables of comparison with the corresponding specific gravities have been experimentally constructed by several distinguished scientific men, which all vary from each other, owing doubtless to the difference of the hydrometers used. Tables IV, and V, give the results obtained by those whose names are above the vertical columns.

Yet the hydrometers of Beaumé, by possessing the advantages of simplicity, cheapness, cleanliness, and adaptation to the liquids for which they are used—solutions of salts, sirups, acids, etc.—and being founded upon known and easy bases of construction, so that they may be made by any workman, have passed into use, notwithstanding the well-known imper-

fections I have mentioned, and to an extent exceeding that of any other hydrometer.

This would be surprising, but for the striking contrast of the advantages mentioned, with the correlative disadvantages of complicated structure, high cost, liability to corrosion, limited application, and patented or secret methods of construction, rendering their manufacture a monopoly, which have justly confined other instruments to particular countries or cities. And here it may be proper to remark, that in our country, as well as in England and France, the Government, by peculiar legislation, has rendered the manufacture of hydrometers for the revenue a monopoly, and that the person who long enjoyed this exclusive privilege was the late Mr. Dycas, of Liverpool, England, whose hydrometer is established by law as that to be used in the United States for determining the strength of spirits. Certainly our own mechanics, if any, should enjoy such privileges. The States of Pennsylvania and Maryland, also, have, by statute, adopted "Dycas's Patent Liverpool Hydrometer" as their standard, and so most probably have other States.

58. Now, an instrument which may be accurately, easily, and cheaply made by any workman, is certainly of a nature which should recommend itself in a republican government. And the decimal hydrometer, which combines all the advantages of the instruments of Beaumé, with a freedom from their defects, and the superiority of being founded upon bases which Nature every where presents, in which there is nothing arbitrary but the system of counting by tens, instead of any other numbers, and the degrees of which are converted into specific gravities by a rule so simple that it may be performed mentally, should certainly be adopted, both by our Government and its citizens.

And, as I have already stated, by adopting that scale for Beaumé's hydrometer, which seems best entitled to credit for exactness, and drawing it upon the same slip of paper with the corresponding degrees of the decimal system, instruments may be furnished by tradesmen which will always be accurate, if regarded simply as *pèse-esprits*, or *pèse-acides*, of Beaumé. And they will cost only the additional labor requisite to draw two scales upon the same paper instead of one.

59. To obtain the modulus and a formula for converting degrees of the hydrometers of Beaumé into specific gravities, we must substitute for y the values given by the solutions of salt, and by distilled water, in our fundamental equation (8.) Now, MM. Francœur and Dulong have given, as the result of very careful experiments, $y = 1.0735$ for the solution of 10 per cent., and $y = 1.1094$ for the 15 per cent. solution.

Hence, for the *pèse-esprit*,

$$p = x - \text{---} - \text{---} - \text{---} - \text{---} - \text{---} \text{ for water;}$$

$$p = 1.0735 x', \text{ -- for the saline solution;}$$

and

$$x - x' = 10^\circ.$$

Hence we have

$$p = \frac{10.735}{0.0735} = 146^\circ \text{ (16.)}$$

Therefore,

$$y = \frac{p}{x} \text{ becomes } y = \frac{146}{136 + x''} \quad (17).$$

In the denominator, we substitute 136, because the zero point is 10 degrees below that of water.

And for the *pèse-acide*,

$$\begin{aligned} p &= x && \text{in water,} \\ p &= 1.1094 x' && \text{in the saline solution;} \\ \text{and} \quad x - x' &= 15^\circ. \end{aligned}$$

Hence we obtain

$$p = \frac{16.641}{0.1094} = 152^\circ \quad (18).$$

$$\text{and} \quad y = \frac{p}{x} = \frac{152}{152 - x''} \quad (19).$$

In the preceding equations, x'' denotes the indication of the scale for which y is the corresponding specific gravity. From these formulas, (17) and (19), tables of comparison with specific gravities may be calculated, possessing far greater accuracy than any obtained experimentally with the instruments to be found in the shops; and such tables would serve to fix the standard scale for Beaumé, which should accompany some of the hydrometers of the decimal system.

60. But as the degrees of hydrometers are merely the fractional parts into which the modulus is divided, it follows, from equations (16) and (18), that, to convert degrees of the decimal system into degrees Beaumé, every 100 degrees decimal are equivalent to 146 Beaumé, for the *pèse-esprit*. Hence we have the rule: *multiply by 146, and divide the product by 100, then add 10 for the difference of the zero points.*

And for the *pèse-acide*, to reduce decimal degrees to Beaumé, *multiply by 152, and divide by 100.* The zero point is the same.

These operations are reversed when we desire to convert degrees Beaumé into decimal degrees.

61. *Cartier's hydrometer, (pèse-esprit).* This instrument would scarcely deserve notice, were it not for the fact that it was employed by the French Government for a long time in levying duties before the centesimal alcoholometer of Gay Lussac was brought forward. Cartier, a goldsmith of Paris, was employed by Beaumé to make metallic hydrometers. Brisson, by his influence, was enabled to prevent the use of Beaumé's hydrometer, though unable to supplant it with his own, reading specific gravities. Cartier divided the scale of Beaumé's instrument, so that every 16 degrees Beaumé should be equal to 15 degrees Cartier. This robbery was not only

tolerated, but the Government even sanctioned it by the adoption of Cartier's instrument. According to M. Francœur, the 22d degree coincides on both scales; hence we have the equation

$$(22 \pm 16) B = (22 \pm 15) C;$$

which will enable us readily to convert indications of Beaumé into those of Cartier, and *vice versa*.

As the bases of construction of Cartier's hydrometer were kept secret, the instrument, founded upon no established data, varied so that it became different from what it was at first. M. Gay Lussac found for several silver hydrometers submitted to his examination by the *Directeur des Contributions indirectes*, that, as Beaumé had stated, 29 degrees Cartier correspond to 31 of Beaumé. Yet these hydrometers differ from those used by the Government in the revenue.

62 *The centesimal alcoholometer of M. Gay Lussac*.—In the little book* of tables and instructions which accompanies this simple and beautiful instrument, it is so briefly and clearly explained, that I will employ the language of M. Gay Lussac, literally translated, instead of giving its description at second hand:

"The spirituous liquors known in commerce as *ardent spirits* are mixtures in various proportions of water and perfectly pure alcohol. Their value, therefore, generally depends upon the quantity of alcohol that each contains. To determine this quantity of alcohol, I take pure alcohol by volume, at the temperature of 15° centigrade, (59° Fahrenheit,) as a term of comparison, and I represent its *strength* by 100 *per cent.*, or unity. Hence, *the strength of a liquor is the per cent., by volume, of pure alcohol which it contains at the temperature of 15° centigrade.*

"The instrument which I call *the centesimal alcoholometer* is, with respect to its form, an ordinary hydrometer. It is graduated at the temperature of 15° centigrade. Its scale is divided into 100 parts, or degrees, of which each represents a per cent. of alcohol; the degree 0 corresponds to pure water, and the division 100 to alcohol. Plunged into a spirituous liquor at the temperature of 15° centigrade, it indicates at once its strength. For example, if in brandy at the temperature 15° it sinks to the division 50, it shows that its strength is 50 per cent.; that is to say, the brandy contains 50 per cent. of its volume of pure alcohol.

"When the liquor is not of the temperature of 15°, a portion is brought to that temperature, either by warming it with the hand, or cooling it by immersion in cold water; but it will be both more convenient and more exact to employ the tables of correction given."

This instrument of M. Gay Lussac is so perfectly simple, and so admirably adapted to the use for which it is designed, that it could not fail to be of the greatest service to commerce, if it should be adopted in place of the complicated, uncertain, and almost unintelligible hydrometers of Sikes, Dycas, and others. The simplicity of this hydrometer renders its cost comparatively trifling. It may be constructed of glass or metal. It is this instrument which, at present, I feel inclined to recommend to the use

* "Instruction pour l'usage de l'Alcoomètre Centésimal et des tables qui l'accompagnent. Par M. Gay Lussac;" Paris, 1824.

of our Government; before deciding, however, the opinions of persons engaged in the manufacture and sale of spirituous liquors should be consulted and carefully considered, and certain experiments should be performed, which would furnish full and complete information upon every important point connected with its theory, that instructions may be given for its construction, which has been kept secret for commercial purposes, and which instructions should be so simple that any good workman may comprehend and carry them into effect. Their manufacture may then be carried on by our own mechanics.

At present, the alcoholometer of Gay Lussac may be purchased in our large cities of persons who import it from France; and, on account of its superiority and low price, it deserves the attention of distillers and dealers in spirituous liquors. In the Dictionary of Arts and Manufactures, by Dr. Ure, (article Alcohol,) and the valuable Encyclopedia of Chemistry of Messrs. Booth and Boyé, (article Alcoholometry,) will also be found the tables of correction for temperature given by M. Gay Lussac.

The Government of Sweden has, at the recommendation, I believe, of the celebrated Berzelius, adopted the centesimal alcoholometer. In Prussia and Austria, similar instruments by Tralles and Meissner have been established by the authority of law. Whether other countries employ it, I have not at present sources of information at command.

As the theory of this instrument will probably be discussed fully in a subsequent report, and after the above-mentioned experiments shall have been performed, I pass to the description and discussion of English hydrometers.

British hydrometers.

63. Of perhaps fifty different instruments which have been used in England, I shall describe but few, and discuss only those of Dycas and Sikes. The first, because it is adopted by act of Congress approved August 10, 1790, as the hydrometer to be used in levying duties in the United States; and the second, because it is employed in the revenue of Great Britain; both of which hydrometers are, however, exceedingly complicated, and therefore very uncertain and imperfect.

64. *Clarke's hydrometer.*—This is the oldest hydrometer established by law for the British Government; it is particularly described by its inventor in the Philosophical Transactions of the Royal Society for the year 1730; and at that early day, when exact knowledge of the dilatation of alcohol and of metals had not been obtained by experiment, the correction for temperature supplied by this instrument, though very imperfect, constituted a decided superiority over other hydrometers in use. The instrument before me was intrusted to the Office of Weights and Measures by the Treasury Department, No. 11,679, made of copper by the hydrometer makers to His Majesty's Honorable Board of Excise. The bulb is about one inch in diameter; the stem very slender, and flat, having the proof point marked by an inlaid silver bead, above and below which it is graduated from one to ten; it is accompanied by thirty-two weights, to adapt it to liquors of different density; and eleven weights for temperature, marked successively from 32° to 80° Fahrenheit, "*very cold, colder, cold, coldish, temperate, warmish, warm, warmer, hot, hotter, very hot,*" which adjectives

are defined by corresponding degrees upon the scale of the accompanying thermometer.

65. The importance of a correction for temperature will be felt, if it be borne in mind that the change of bulk of spirit containing 50 per cent. of alcohol is such that there is a difference of two gallons and a half in every hundred, according to the experiments of Gilpin, produced by a variation of temperature from 32° to 80° Fahrenheit, which for our purposes may be considered as the temperatures of summer and winter for the mean climate of the United States. The rise and fall of the liquid in the tube of a thermometer is a familiar instance of this change of volume by variation of temperature.

66. The system of describing the strength of liquors corresponding to Clarke's hydrometer, and given by numbers engraved upon the weights, was as follows: For spirits *over proof*, 1 to 2, 1 to 3, 1 to 4, &c., implied one gallon of water must be mixed with two, three, four, etc., respectively, of liquor, to reduce it to proof. And for spirits *under proof*, 1 in 2, 1 in 3, 1 in 4, etc., denoted that one gallon of water taken from 2, 3, 4, etc., would reduce the liquors to *proof* spirit.

By act of Parliament, 1762, the specific gravity of proof spirit was established as 0.916 at 60° Fahr. But the proof spirit of Clarke's hydrometer was in error 0.004, as shown by the following table of Lowitz for the indications of that instrument:

Hydrometer.	Sp. gravity.	Hydrometer.	Sp. gravity.
1 in 2	0.9644	1 to 20	0.9162
1 in 5	0.9424	1 to 15	0.9135
1 in 10	0.9320	1 to 10	0.9107
1 in 15	0.9280	1 to 5	0.8961
1 in 20	0.9265	1 to 2	0.8590
Proof	0.9200	Alcohol	0.8338

By subsequent act of Parliament, the proofs of Clarke's hydrometer were fixed relatively to those of Sikes's hydrometer, as follows:

Clarke's.

One to nine over proof
One to ten over proof
One in eight under proof
One in six under proof
One in five under proof

Sikes's.

= nine per cent. above proof.
= seven per cent. above proof.
= thirteen per cent. under proof.
= seventeen per cent. under proof.
= twenty-two per cent. under proof.

The duties were charged only upon proof spirit, and a calculation had to be made, to ascertain the quantity thereof contained in any liquor.

67. Owing to the imperfections of Clarke's hydrometer, it was abandoned and Jones's, Quin's, Dycas's, Speer's, Atkins's, and Sikes's hydrometers came successively into use. The first three of these were substantially the same as Clarke's, and may be considered simply as improvements rendered necessary by its faults, and performed but imperfectly, for want of thorough knowledge.

I shall describe Dycas's hydrometer among those of the United States; but it were useless to give a detailed account of the instruments which went into disuse when the Government of Great Britain adopted the hydrometer of Sikes, and which seem to have been contrived to suit the system of *proofs* established in trade by the use of Clarke's hydrometer, and therefore to have produced no permanent and material effect upon the practice of that Government. Besides, as these hydrometers possess no superiority, they are therefore objects of curiosity rather than of scientific consideration.

68. In consequence of the confusion and want of certain knowledge with which the subject of hydrometers seemed to be invested, the British Government applied to the Royal Society; at the recommendation of which, a laborious and accurate series of researches were undertaken and performed by Sir Charles Blagden and Mr. Gilpin; the results of which were published in full in the transactions of that society for the years 1790, 1792, and 1794. The accuracy and fidelity with which this task was performed, and the refinement of the methods employed, entitles these researches to all the admiration and praise that has been so liberally bestowed upon them by those who have taken the pains to examine them; and it would perhaps be but justice to say, that they would do honor to the more refined science of our day, when the art of philosophical instrument making has been carried to a degree of perfection which is indeed wonderful, and the sister art of experimenting has become a calling which can be learned only by serving an apprenticeship under a skilful and experienced master.

It is a fact, strange and unaccountable as it may appear, that though Messrs. Gilpin and Blagden performed their task in a manner which could not have been surpassed, and obtained nearly all the information requisite to furnish a perfect instrument and system of inspection for spirits, the British Government neglected to apply the knowledge obtained to its legitimate object. And, twenty years afterwards, the complicated, imperfect, and uncertain hydrometer of Sikes was established by law as that to be used in the Revenue of the United Kingdom; though its basis and method of construction are to a great extent arbitrary, and seem to have been kept secret by its inventor, perhaps for purposes of personal emolument.

In Prussia, however, the labors of Messrs. Blagden and Gilpin produced better fruit; for they were there employed by Tralles, who founded upon them his *centesimal alcoholometer*, and method of levying duties by per cent. of alcohol. These were adopted by the Prussian Government; and they differ in no material respect from the similar system established at the suggestion of M. Gay Lussac by the Government of France.

Nor was this action of the British Government owing to any want of proper instruction on the part of Messrs. Blagden and Gilpin; for in his report Mr. Blagden remarks,* after speaking of the requisite points of attention to render a hydrometer adapted to the purpose: "I am still of the opinion that the best way of laying the duty would be directly on the quantity of alcohol contained in any composition." He then proceeds to show how tables may be constructed for this object for each temperature and indication, which will give a "decimal multiplier;" which use of a decimal multiplier, the ratio of the alcohol to the whole mixture, is no other

* See Philosophical Transactions, 1792, p. 436.

than the method of per cent. by volume of Tralles and Gay Lussac, so highly esteemed, in the commerce of their respective countries, for its accuracy, convenience, and simplicity.

69. *Sikes's hydrometer*.—I describe the instrument furnished by the Treasury Department to the Office of Weights and Measures, and made by R. B. Bate of London, "hydrometer maker for the Revenue of the United Kingdom," established 22d July, 1816, by act of Parliament, (58 George III., cap. 28,) and accompanied by a thermometer and a book of tables containing 62 pages quarto and entitled "Sikes's table of the concentrated strength of spirits, with directions for the use of his hydrometer." This hydrometer is of brass, and consists of a spherical bulb about one inch and a half in diameter, to which is attached below a slender conical rod about one inch and a quarter in length, which carries at its end a counterpoise of a half inch nearly in diameter, to give it the requisite stability. Above the bulb is attached the stem, flattened and graduated *with a single scale* into ten equal divisions, numbered from 1 to 10, which are again subdivided into five fractional parts of two tenths each. The length of this stem is about three and one-half inches, and the entire length of the instrument is six and one-half inches nearly.

The instrument is accompanied by nine different weights, of *unequal volume*; the form of which is that of a divided ring, so that they may be placed upon the conical rod, and then slid down to the counterpoise, where the increased diameter of the cone prevents their falling off in the liquid. By means of these weights, numbered 10, 20, 30, etc., to 90, the hydrometer scale is extended to 100 divisions, of which the units are read off upon the graduated stem, and the tens are given by the weights. If we consider the fractional parts of two tenths each, then the scale comprises 500 divisions.

On the side or edge of the stem there is a mark to which the weight 60 depresses the instrument in *proof spirit* at 51° Fahr. By the act of Parliament establishing the use of this hydrometer, *proof spirit* is defined to be *that which at 51° Fahr. weighs exactly twelve-thirteenths of an equal bulk of distilled water*. The hydrometer is therefore accompanied also by a small square weight, having a hole in one side by which it may be fixed upon the top of the graduated stem, and which weighs one-twelfth of the entire weight of the instrument and weight numbered 60. When added, this square weight sinks the hydrometer in distilled water to the proof mark, and shows that the instrument is constructed in accordance with the definition of the act of Parliament.

The thermometer is of Fahrenheit's scale; and the book of tables shows for every indication and temperature, from 30° to 80° Fahr., the corresponding *over proof* or *under proof*.

This hydrometer is sometimes accompanied by a "sliding rule," somewhat like that which is used for Dycas's hydrometer, and which gives the strength, mechanically, by causing the star to coincide with the observed temperature, and then reading off the proof opposite the indication or division given by the hydrometer.

70. There are two serious objections to the use of a hydrometer of this description; the first arising from the fact that weights of unequal volume are added below the surface of liquids of different density, which renders

the theory of the instrument so complicated as to be incomprehensible to workmen generally, and requires, for its construction to attain certainty, an amount of mathematical calculation which should not be demanded, as there is no necessity for it. And should the instrument maker follow the process of servilely copying one instrument from another, then it seems to me there can be no ground for confidence in his work. The second objection is, that a single divided scale upon the stem causes the divisions to correspond to a different arbitrary system of graduation for each successive weight and modulus; thus destroying all unity and simplicity.

The force of these objections will be better felt by an inspection of the mathematical theory of Sikes's hydrometer, which I give as developed by M. Franceur in his valuable memoir already referred to, (art. 32,) and which is not, as far as I am aware, to be found in any English publication.

71. The instrument should be of such volume and weight, that, when floated in absolute alcohol, a small portion of the stem will be above the surface of the liquid; and when plunged into water, an additional immersed weight should cause the surface to be a little above the bulb. That these conditions, requisite to fix the zero point and division 10 of its scale, may be fulfilled, it is necessary to perform the following preliminary experiments.

Having weighed the instrument, add weights *internally*, or *at the top of the stem*, until it sinks in distilled water to the division 10, just above the bulb. The entire weight thus given, and which we denote by v' , will, as the density of water is known, determine the volume of water displaced. Then add weights, in a similar manner, until the hydrometer sinks to a point near the top of its stem, which should be taken as the zero point; denote this second weight by v ; we shall thus obtain $k = v - v'$; and these weights $v - v'$ and k will give the volumes corresponding respectively to the zero point, to division 10, and to the graduated portion of the stem.

Now since, by equation (8), $p = xy$, if Π be the density of absolute alcohol, it becomes necessary to the end, that the hydrometer shall sink in alcohol to the zero point, that it should fulfil the condition

$$p = \Pi v \quad \text{---} \quad (20).$$

In which equation, p is the weight of the instrument without its additional weights.

That it may sink in distilled water to division 10, we must add a weight upon the conical rod *beneath the surface*, equal to m grains; if d represents the specific gravity of the metal, then will m , divided by d , be the volume beneath the surface. So that division 10 will correspond to the volume and equation,

$$v' + \frac{m}{d} = p + m;$$

the density of water being unity. Hence we obtain

$$m = (v' - p) \frac{d}{d - 1} \quad \text{---} \quad (21).$$

And the two fundamental conditions, that it should sink in absolute alcohol to zero, and with an additional immersed weight m to division 10 in distilled water, by equations (20) and (21), are fulfilled.

If the hydrometer sinks to its zero point in a liquid of which the density is denoted by δ ; and, when loaded with one of its weights ϕ , then will

$$p + \phi = \delta \left(v + \frac{\phi}{d} \right) \quad (22).$$

And that it may sink in the same liquid to division 10, we substitute a different weight ϕ' , which is lighter; and

$$p + \phi' = \delta \left(v' + \frac{\phi'}{d} \right);$$

by elimination,

$$\frac{p + \phi'}{p + \phi} = \frac{v' + \frac{\phi'}{d}}{v + \frac{\phi}{d}};$$

hence

$$(\phi - \phi') \left(v - \frac{p}{d} \right) = (p + \phi) \cdot (v - v') = k (p + \phi);$$

and putting

$$k = n \left(v - \frac{p}{d} \right) \quad (23)$$

we get

$$\phi' = \phi (1 - n) - n p \quad (24).$$

When, therefore, the hydrometer is loaded with the weight ϕ , and sinks to zero, it will sink only to division 10°, if the weight ϕ' be substituted in its place.

72. Suppose that we make $\phi = m$ the weight which causes the hydrometer to sink to division 10; then will the indication be read off as 100°, since $m = 90$.

Then, in a less dense liquid, in which the weight 90 causes the hydrometer to sink to zero, the indication will be 90; if we replace this weight ϕ by another ϕ' , which shall sink it only to division 10, we shall have $\phi' = 80$; and if we substitute ϕ' for ϕ , we may, in a similar manner, obtain $\phi'' = 70$; and so on. Thus we shall obtain, successively, each of the weights, from 90 downwards to 10, of the series which constitutes the scale of the hydrometer.

As the weights are of copper, the specific gravity of which is 8.396, we shall have

$$m = 1.1352 (v' - p) \quad (25).$$

$$n = \frac{k}{v - 0.119 p} \quad (26).$$

From equation (22) we obtain

$$\delta = \frac{p + \phi}{v + 0.119 \phi};$$

which gives the specific gravity of the liquid in which the weight ϕ sinks the thermometer to zero.

M. Francœur found a hydrometer of Sikes to weigh $p = 29.65$ grammes, and that the volumes immersed corresponding to 0° and 10° were respectively $v = 36.25$ and $v' = 35.52$ cubic centimetres; hence $k = v - v' = 0.73$ cubic centim. The weight requisite to sink the instrument to 10° in water was therefore $m = 6.663$ grammes; and $n = 0.0223$ and $1 - n = 0.9777$. From which data M. Francœur constructed the following table:

Degrees.	Additional weight, in grammes. m .	Specific gravity of spirit. δ .	Degrees.	Additional weight, in grammes. m .	Specific gravity of spirit. δ .
90	6.663	6.9804	40	2.793	0.8869
80	5.856	0.9608	30	2.073	0.8692
70	5.064	0.9420	20	1.367	0.8518
60	4.290	0.9233	10	0.675	0.8347
50	3.533	0.9049	0	0.000	0.8179

73. I would here remark, that, according to M. Francœur, the hydrometer of Sikes is no other than that which had been long in use in Montpellier, and which was invented by Dr. Bories, who based it upon accurate experiments of his own. Mr. Sikes professes to have calculated his tables from the data furnished by Messrs. Gilpin and Blagden. The hydrometer of Sikes too closely resembles that of Mr. Atkins and others which preceded it, to render it probable that he merely copied after Dr. Bories; such, however, may possibly have been the fact. For a description of Bories's hydrometer, M. Francœur refers to the *Bulletin de la Société d'Encouragement*, 5e. année 1806, p. 185. In a subsequent section of this report will be found experiments of comparison and verification for Sikes's hydrometer.

74. According to Dr. Ure,* the Lords of the Treasury recently requested the Royal Society to examine the construction of Sikes's hydrometer, and its fitness for its purpose. Of the action of the Society upon this application I have been unable to find any account, either in its Transactions or Bulletins of proceedings. Dr. Ure states, however, that a committee was appointed, who recommended a different system, and the use of a hydrometer reading specific gravities. Mr. Bate, the hydrometer maker for the Revenue, brought forward a new instrument, a peculiarity of which is, that the additional weights differ successively in volume by a quantity equal to the portion of the stem which forms the graduated scale; this would add greatly to the trouble and difficulty of manufacture, and consequently to

* See Ure's Dictionary of Arts and Manufactures, article Alcohol, page 20, London edition.

the cost. Mr. Lubbock seems to have been intrusted with these investigations, and the report of the committee, to which Dr. Ure furnishes no reference, is, I have reason to believe, contained in the Parliamentary papers. The well established and high reputation of Mr. Lubbock entitles any thing coming from his pen to careful consideration; therefore, and because no change has yet been made, as far as I have been able to learn, in the system of Great Britain with relation to these matters, I shall defer all further remarks until I shall have succeeded in obtaining the report made by the committee of the Royal Society upon this subject.

Omitting all notice of other and comparatively unimportant English hydrometers, which are not few in number, I pass to the discussion of those employed in other countries.

Hydrometers of Prussia.

75. *Centesimal alcoholometer of Tralles.*—This instrument may be regarded as the same as that of M. Gay Lussac, from which it differs very slightly; the specific gravity of water is taken by Tralles as unity at the temperature of its maximum density, so that it becomes 0.9991 at 60° Fahrenheit. Gay Lussac assumes it to be unity at the temperature of 15° centigrade. Again, M. Gay Lussac defines *absolute alcohol* as that which possesses the specific gravity of 0.7947 at the normal temperature, 15° centig.; while Tralles assigns to it the specific gravity of 0.7939 at 60° Fahrenheit. These temperatures differ by one degree Fahrenheit, which would cause a variation in specific gravity of 0.0005 only; to be added to that given by Tralles, which becomes 0.7944. The difference 0.0003 is sufficiently accounted for by the different units selected, and by the well-known fact, that the zero points of thermometers become somewhat displaced after manufacture and by use; hence, this discrepancy falls within the limits of instrumental errors.

The researches of Tralles were published in the year 1811;* the results of those of M. Gay Lussac in 1824. Tralles bases his tables upon the weighings of Messrs. Gilpin and Blagden; M. Gay Lussac upon experiments of his own which he has not made public. The tables given by M. Gay Lussac in the little book to which I have referred are far more complete than those of Tralles, or any others extant. These tables are also contained in full, as well as those of Tralles, in the *Encyclopedia* of Messrs. Booth and Boyé (art. *Alcoholometry*), and they well deserve the praise bestowed upon them by Dr. Ure in the remarks:†

“I consider the preceding table, which I have extracted from the longer tables of M. Gay Lussac, an important addition to the resources of British dealers and manufacturing chemists. With his little instrument, the real value of any spirituous liquor may be determined to sufficient nicety for most purposes, and by a far easier manner than by any instruments now used in this country.”

Tralles has given full instructions for the construction of his centesimal alcoholometer; these are not published for the instrument of Gay Lussac,

* See Untersuchungen über die specif. Gewichte der Mischungen aus Alkohol und Wasser, und Tafeln für den Gebrauch und die Verfertigung der Alkoholometer, vom Prof. Tralles, Secret. d. math. Klasse d. Akad. d. Wissensch. zu Berlin. In *Annalen der Physik*, von L. W. Gilbert, Jahrgang 1811, Stück 8.

† See Dr. Ure's *Dictionary of Arts and Manufactures*, London edition, p. 28, art. *Alcohol*.

the manufacture of which seems to be secured by patent to MM. Gay Lussac and Collardeau. M. Collardeau, a pupil of the Polytechnic school, was the assistant of M. Gay Lussac in his labors.

76. *Richter's Alkoholometer*.—The instrument which has borne this name is simply a hydrometer of the ordinary construction, graduated so that its degrees shall indicate the per cent. of alcohol, *by weight*, contained in a spirituous liquor. It is inferior in convenience and utility to that of Tralles, which gives per cent. *by volume*, because liquors are bought and sold by measure instead of weight.

This hydrometer has been constructed of several kinds, based upon different data ;* the first was founded upon Richter's earlier researches, and showed the per cent. of alcohol of the specific gravity 0.821 ; the second upon Lowitz's tables, making the specific gravity of absolute alcohol 0.791 at 16° Reaumur ; and the third upon Richter's later determinations, giving 0.792 for the specific gravity of absolute alcohol.

Richter also founded his hydrometer upon but five observations interpolated arbitrarily, and made only at the single temperature of 16° Reaumur. As he retained this basis even in later constructions, it is strange that his instrument gave determinations so approximate to truth.

77. The hydrometer now constructed and known in Prussia by the name of *Richter's alkoholometer*, is a very different instrument, based upon the labors of Tralles and observations of Messrs. Gilpin and Blagden,† which possess all requisite exactness.

78. *Alkoholometer of Lowitz*.—According to Meissner, although Lowitz never gave his attention to the subject of constructing a hydrometer, yet many instruments were founded upon his tables, published in *Crell's Annalen*. Richter set the example, and many artists followed it, in Russia, Poland, and Germany ; so that hydrometers, founded upon Lowitz's determinations, became common, and most of them bore the name "*Alkoholometer nach Lowitz*."

79. *Universal areometer of Richter*—(*allgemeines Aräometer*.)—This instrument was intended to read specific gravities ; but Richter fell into the error of supposing that a scale graduated into equal parts would give equal variations of specific gravity. We have seen that, for this purpose, the divisions should vary with the ordinates of a hyperbola referred to its asymptotes. Poggendorff states that the inaccuracy and inconvenience of this instrument have caused it to pass entirely out of use.

80. *Schmidt's Aräometer*.—This is a hydrometer so constructed as to read specific gravities with accuracy ; the geometrical construction for which is described in (Gren's N. Journal d. Physik, 1796,) and also by Poggendorff, in his excellent article on *Aräometrie*, in the *Handwörterbuch der Chemie*.‡ The above-mentioned hydrometers are made by J. J. Greiner, of Berlin,

* See Meissner's *Aräometrie*, Wien, 1836, p. 129.

† *Handwörterbuch der Chemie*, von Liebig, Poggendorff, und Wöhler. (pp. 264 und 474.) Braunschweig, 1842.

‡ *Aräometrie*, p. 180, § 325.

with a degree of skill which probably surpasses, for such instruments, that of any other artist in Europe.

In Austria.

81. *Meissner's Alkoholometer*—An instrument consisting of a combination of the scale of per cent. by volume with that for per cent. by weight, and founded upon independent experiments and determinations by its author, has long been in use as the hydrometer of the Government of Austria. This instrument, bearing two graduated scales, may therefore be considered as a union of Richter's scale with that of Tralles. As the data differ upon which the centesimal alcoholometers of Tralles, Gay Lussac, Meissner, and Richter, are founded, the indications will not correspond exactly. (Table VI of the appendix will serve to show their differences.)

82. *Universal Areometer of Meissner*—(*allgemeines Aräometer*.)—This hydrometer reads specific gravities from 0.700 to 2.000. The divisions of its scale are unequal in volume, and the instrument is therefore liable to all the objections already urged with reference to hydrometers graduated to indicate specific gravities. To what extent it may be in use, I have no means of ascertaining; it is described in *Meissner's Aräometrie*, already referred to; a work regarded in Germany as high authority upon the subject of which it treats, and a copy of which my friend, Professor J. C. Booth, has kindly placed at my service.

83. Professor Meissner has also described, in his valuable treatise, several *special hydrometers*, (*besondere Aräometer*), so constructed as to show the quantity of the substance which imparts value to the liquid. One of these (*Schwefelsäuremesser*) is intended for sulphuric acid; others, analogous to it, are adapted to nitric acid and hydrochloric acid; another is applicable to ammonia. And he has constructed tables which give the specific gravities corresponding to every five per cent., from zero to one hundred.

The Holland hydrometer.

84. The medical faculty of Amsterdam adopted a modification of Beaumé's hydrometers, which has since been known as the Holland hydrometer, (*das holländische Aräometer*), or hydrometer of the *pharmacopœa batava*, 1805. Beaumé, as we have seen, employed solutions of common salt for his hydrometer for spirits (*pèse-esprit*), and 15 per cent. for his hydrometer for liquids heavier than water, (*pèse-acide*.) Water, which corresponds to 10 of the *pèse-esprit*, marks the zero point of the *pèse-acide*. The *Holland hydrometer* has the specific gravity of water 1.000 at 10° Reaumur, (54½° Fahrenheit,) for the density corresponding to its zero point. The 10th degree of its scale is determined by a solution containing 10 per cent. of its weight of common salt; and the degrees are all equal, both above and below zero.

In Switzerland.

85. *The hydrometer of Beck*, an instrument maker of Bern, has become very generally known. It is sometimes called *Bentely's hydrometer*;

and is merely a modification of *Beaumé's*, proposed by Bentely, having the density of water at 10° Reaumur for that of its zero point, while its 30th degree is determined by a liquid of the specific gravity of 0.850. This instrument is therefore free from the errors which are produced in the graduation of *Beaumé's* hydrometer by the use of the method of repetition of units to extend the scale, instead of that subdivision of a multiple. The divisions of its scale are also equal, whether positive or negative.

Hydrometers of America.

86. *Hydrometer made by Tucker & Dwyelle, of Boston.*—This instrument is accompanied by a thermometer and sliding rule. That which has been submitted by the Treasury Department is marked No. 81. It is of silver; this adds considerably to its cost, but is deemed by the makers a great advantage, for the assigned reason, that it is less liable to corrode than copper. This hydrometer is accompanied by ten additional weights, which, in form and in the manner of their application upon a conical rod connecting the bulb and counterpoise, are identical with the construction of *Sikes's* hydrometer. Although the scale of this hydrometer reads from zero to 100 instead of from 100 to zero, as in *Sikes's*, and although the sliding rule professes to be adapted to the American system of proofs, it still seems to me that this is no other than *Sikes's* hydrometer under a new name, and in a dress of the American fashion.

87. *Southworth's hydrometer.*—This instrument is established by law of the State of New York as the standard for that State. Apart from the question of accuracy of construction, it possesses merit; for the divisions of the scale indicate per cent. above or below proof directly, and without recourse to any sliding rule or set of tables. The proof mark is thus the zero point of graduation. This arrangement appears to be much simpler than any other which has been brought forward to determine the strength relating to proof spirit; and it deserves consideration, if the present system of proofs be continued. But in simplicity no instrument compares with the centesimal alcoholometer of Tralles and Gay Lussac. The workmanship of the instrument belonging to the Treasury Department appears to be very rough, and its graduation inaccurately performed. I regret that it was not in my possession when I performed the experiments of comparison given in a subsequent part of this report. But I doubt very much its accuracy; and the rule given by Mr. Southworth of correction for temperature appears to be no other than that of M. Francœur for the alcoholometer of M. Gay Lussac, with this great oversight, if it be so, that degrees Fahrenheit are substituted in place of degrees centigrade, without reduction. But I dismiss the expression of surmise, and defer all further remarks upon this instrument until experiments with it shall have put me in possession of all necessary facts.

88. *Dycas's hydrometer.*—The theory of this hydrometer has been already partially set forth in my general discussion of the theory of hydrometers; and particularly in articles 40, 45, 46, and 54. The instrument before me, made by Fisher, of Philadelphia, No. 342, belongs to the Treasury Department, and is similar to those now in use in the revenue of the United States. It is copied strictly after one made by the late Mr. Dycas, of Liverpool, which is used by Mr. Fisher as a standard.

The bulb is an oval gilded copper or brass ball, about one inch and a half in diameter; to this ball is fixed a slender stem, graduated in equal divisions of a *single* scale, and terminating in a point which fits the holes at the centres of the different weights; by that means they are attached when the hydrometer is in use. Below the bulb, a counterpoise is fastened to the end of a rod in the ordinary manner. The whole instrument is about seven inches long; and it is accompanied by thirty-six circular perforated weights, marked 0 to 350, which is the lightest. At the top of the stem is stamped the number 360, which corresponds to the instrument without weights, and enables the scale to be extended to 370. In the same box with the hydrometer are also a Fahrenheit thermometer, and an ivory sliding rule.

The instrument has therefore a series of 370 indications; but as the moduli vary with the weights, the degrees will not belong to a single system, and the scale may be in fact regarded as a combination of thirty-seven different scales. The hydrometer indications are marked upon the slide, or middle portion of the sliding rule, from 0 to 370, water being zero; and the corresponding strengths above and below Dycas's proof spirit are marked upon the margin, or fixed part of the rule, opposite to the indications. To adapt this instrument to different temperatures, as shown by the accompanying thermometer, the left hand part of the slides has upon its side a graduated scale from 30° to 80° Fahrenheit. And when the index upon the margin is placed opposite the temperature observed, then will the indication observed correspond to the particular strength of the liquor examined.

To obtain a formula by which to calculate the values of the successive weights of Dycas's hydrometer, we must pursue a train of reasoning somewhat analogous to that of M. Francœur for Sikes's hydrometer, developed in article 71. Having first weighed the instrument itself, we ascertain the respective volumes displaced when it sinks in water at 40° Fahrenheit to its zero point and to division 10 of the stem, by adding known weights and calculating the volumes therefrom. Call these volumes v and v' ; then will $v' - v$ be the volume of the graduated portion of the stem, and we will represent it by k .

Denote the weight of the hydrometer alone by p , and suppose that when loaded with the additional weight w it sinks to zero, then, if we add a second weight which shall be equal to $k d$, the hydrometer will sink to division 10 of the scale, d being the density of the liquid. Hence,

$$w' = w + k d;$$

For the density d we have

$$d = \frac{p + w}{v} \quad \dots \dots \dots (28);$$

and, therefore,

$$w' = w (1 + n) + p n \quad \dots \dots \dots (29);$$

making k , divided by v , equal to n .

The difference of the specific gravities of the liquids in which the same

weight w causes the hydrometer to sink to zero in the one and to division 10 in the other, will be

$$d - d' = (p + w) \left(\frac{v' - v}{vv'} \right) = (p + w) \frac{n}{v} \quad (30);$$

we shall have

$$d - d'' = (w - w'') \frac{1}{v} \quad (31),$$

for the relation between any two specific gravities and the weights which cause the corresponding indications to be each equal to zero.

I have now described nearly all the important hydrometers in general use. There are others, such as Allen's, Bate's, Richardson's, Dycas's, and Southworth's saccharometers for brewers, and Twaddle's hydrometer for fluids heavier than water, which may hereafter be discussed. But, for the present, omitting to do any thing more than mention their names, and reserving all further remarks upon Dycas's hydrometer, as well as a more particular account of the ivory sliding rule which accompanies it, for the sequel, I pass to the next division of my report.

On the temperature of the maximum density of water.

90. The practical importance of determining the temperature at which water attains its maximum density, and the law of its dilatation for variations of heat near that temperature, is apparent, from the reasons already given why it should be employed to fix the modulus or zero point of hydrometers. But as this temperature is also adopted by Governments, and our own among the number, for the establishment of accurate weights and measures, it becomes of the highest interest and necessity, apart from mere scientific considerations, to ascertain it with all possible refinement, both of experiment and calculation.

So many distinguished scientific men have devoted their attention to this subject, and tasked their ingenuity to discover methods of refined observation, that it seems scarcely practicable in the present state of experimental science, and of our knowledge of the laws of heat, to invent methods or apparatus more exact than those which have been already employed. Yet, as the philosophical instrument makers of our day accomplish almost miracles in perfection of workmanship, and the impossibilities of one generation become the every day performances of the next, it is unphilosophical to prescribe limits to our progress either in Art or Science. The precise determination of the temperature of maximum density is beset with difficulties which depend upon the very circumstance which gives to that temperature its great advantage and convenience in practical applications. On either side of the maximum, a very considerable difference of temperature scarcely produces a sensible variation of density or volume. Hence the problem becomes that of determining a constant by the measurements of almost inappreciable magnitudes. The density is statical and the temperature dynamical, a combination the most advantageous for measurements of the density, but the most disadvantageous for determining a particular temperature as a function of the density.

It is not therefore surprising to find variations of even one or two degrees in the experiments which have been made with more or less care, and by different individuals.

And when we bear in mind that thermometers made by the same person usually give discordant results, and that even the same thermometer suffers in use, displacement and oscillations of its zero point, amounting often to a degree or more, we will rather find cause of wonder in the approximate accordance of the determinations, than in their want of perfect agreement, which serves only to establish the honesty of the witnesses who testify.

The following table, obtained chiefly from determinations compiled by Hallstrom,* comprises nearly all that have been made :

Observer.	Calculator.	T.	Diff.	Observer.	Calculator.	T.	Diff.
Deluc -	Biot -	3.42	— 0.58	Hope -	Hope -	3.33	— 0.67
" -	Ekstrand -	3.60	— 0.40	" -	" -	3.88	— 0.11
" -	Paucker -	1.76	— 2.24	" -	" -	4.16	+ 0.16
" -	Hällstrom -	1.76	— 2.24	Tralles -	Tralles -	4.35	+ 0.35
Dalton -	Dalton -	2.22	— 1.78	Hassler -	Hassler -	4.35	+ 0.35
" -	Biot -	4.35	+ 0.35	" -	" -	4.11	+ 0.11
Gilpin -	Young -	3.89	— 0.11	Hällstrom -	Hällstrom -	4.34	+ 0.34
" -	Biot -	3.89	— 0.11	" -	" -	3.87	— 0.13
" -	Eytelwein -	2.59	— 1.41	" -	" -	4.165	+ 0.16
" -	Walbeck -	0.44	?	" -	" -	3.897	— 0.103
" -	Hällstrom -	3.82	— 0.18	Muncke -	Muncke -	3.5	— 0.5
Schmidt -	Eytelwein -	2.91	— 1.09	" -	" -	3.78	— 0.22
" -	Hällstrom -	8.63	?	" -	Hällstrom -	3.94	— 0.06
Charles -	Biot -	3.99	— 0.01	" -	" -	3.82	— 0.18
" -	Paucker -	3.88	— 0.12	" -	" -	4.13	+ 0.13
L. Gineau -	L. Gineau -	4.44	+ 0.44	" -	" -	3.81	— 0.19
Bischoff -	Bischoff -	4.06	+ 0.06	Stampfer -	" -	3.93	— 0.07
Ekstrand -	Ekstrand -	3.60	— 0.40	" -	" -	3.63	— 0.37
" -	" -	3.90	— 0.10	Despretz -	Despretz -	4.00	— 0.00
Rumford -	Rumford -	4.38	+ 0.38	" -	" -	3.987	— 0.013
" -	" -	3.47	— 0.53	" -	" -	4.007	+ 0.007
				Rudberg -	Rudberg -	4.02	+ 0.02

The temperatures are given in degrees centigrade; and the column marked *Diff.* is obtained by taking the differences between each observation and 4° centigrade, which may be considered the mean of the more probable observations.

91. The remark contained in the last article concerning the variation of the zero point of thermometers, is based upon the following facts: MM. Arago and Gay Lussac observed (in 1817) that the zero of the thermometer in the cellar of the observatory of Paris had risen 0.38. This want of constancy various observers have since verified; and M. Despretz, who has devoted particular attention to the subject, has shown that the variation, though ascending for several years, suffers oscillations; and that, contrary to the general opinion, the zero, when it has attained its maximum elevation, and even after many years, still continues to oscillate about a mean point.†

* See Ann. de Chim. de Phys. t. 28, p. 56.

† See Ann. de Chim. de Phys., t. 64, p. 312, 1827.

From his valuable memoirs, I have extracted the following results, and arranged them in tabular form :

Thermometer.	No. 1.	No. 2.	Thermometer.	No. 3.	No. 4.	No. 5.
Date.	Zero.	Zero.	Date.	Zero.	Zero.	Zero.
August 30, 1832	0°. C.	0°. C.	November 9, 1832	0°. C.	0°. C.	0°. C.
September 3, 1832	0.11	0.03	after boiling	-0.31	-0.36	-0.06
September 5, 1832	0.14	0.05	Novem. 11, 1832	-0.20	-0.13	0.18
October 6, 1832	0.19	0.13	Novem. 21, 1832	-0.04	-0.10	0.19
November 8, 1832	0.20	0.18	December 1, 1832	0.	-0.03	0.25
December 3, 1832	0.22	0.20	April 7, 1833	0.08	0.13	0.36
January 5, 1833	0.22	0.20	April 4, 1834	0.08	0.03	0.40
April 7, 1833	0.29	0.22	July 25, 1834	0.08	0.10	0.42
April 8, 1834	0.37	0.33	April 17, 1835	0.27	0.21	0.46
April 20, 1834	0.35	0.31	October 2, 1835	0.24	0.24	0.54
April 17, 1835	0.37	0.35	September 4, 1836	0.30	0.24	broken.
October 2, 1835	0.42	0.39	December 5, 1836	0.	-0.07	
October 29, 1835	0.42	0.42	December 5, 1836	-0.06	-0.12	after boiling.
September 21, 1836	0.42	0.42	January 4, 1837	0.08	-0.10	
February 5, 1837	0.46	0.45	January 22, 1837	0.20	0.10	before boiling.
February 9, 1837	0.47	0.45	January 22, 1837	0.12	-0.13	after boiling.
February 21, 1837	0.46	0.45				
June 4, 1837	0.44	0.45				
June 23, 1837	0.42	0.42				

The sensibility of the thermometers was such, that they could be read to the hundredths of degrees with accuracy. The total variation of No. 1 was 0°.47, and of No. 2 it was 0°.45; it was ascending from August, 1832, to February, 1837, a period of four years and five months. In the same interval, two other thermometers (No. 6 and No. 7) varied respectively 0°.23 and 0°.30; while another (No. 8) varied between 23d November, 1832, and 20th March, 1837, to the extent of 0°.57.

These thermometers were made in 1832, and served for experiments during the interval, which is the cause why the variation was sometimes even retrograde. M. Despretz considers it established by his observations, of which he professes to have made many which are not yet published, that the zero points of thermometers are sensibly affected by the atmospheric variations, and that they *fall in summer* and *rise in winter*; while thermometers kept in places where the temperature is constant ascend uniformly, without oscillations, to a maximum at which they remain stationary. The preceding experiments, and particularly those made in 1836 and 1837, with Nos. 3 and 4, establish the fact, that high degrees of heat cause the zero point to fall, and that it ascends, on the contrary, if subjected to low temperatures; also, that the oscillation may amount to even a half degree of the centigrade thermometer, or a whole degree nearly of Fahrenheit. It has therefore been justly remarked by M. Pouillet, (Phys. 1e part. chap. 1.) that, though ignorant of its cause, we can have no doubt of the fact itself, and that therefore all observers should verify the graduations of their thermometers. It does not appear that the observers who have undertaken to fix the temperature of the maximum density of water paid sufficient attention to the verification of the zero point, or origin of measurement; and certainly linear measurements are but half made when the

position of only one of the ends of a line is determined. It is on this account that I attach higher value and attribute greater accuracy to the experiments of M. Despretz than to any others, and that I have chosen 4° centigrade, the mean of his results, as the most probable value. M. Hållstrom, it is true, has taken a great deal of mathematical pains to calculate, by the refined though laborious method of least squares, the probable mean of the more accurate experiments made without regard to the variation of the zero point. And his calculations have served to show that the point of maximum density lies somewhere between the limits of $4^{\circ}.34$ and $3^{\circ}.87$ centigrade, which differ $0^{\circ}.47$ centigrade, or $0^{\circ}.85$ Fahrenheit; the mean $4^{\circ}.1$ differs slightly from the determination of M. Despretz. Hållstrom himself comes to the conclusion, from his calculations, that the temperature of maximum density cannot be determined without leaving upon its value an uncertainty of one-quarter of a degree centigrade. And by a discussion of the probable errors he proves that, for values smaller than $3^{\circ}.678$ centigrade, or greater than $4^{\circ}.583$ centigrade, the probability is infinitely small, and that they must therefore be rejected. This distinguished philosopher has clearly shown in his valuable memoir* the necessity of discussing, by calculations of the greatest rigor, experiments made to determine a value that depends upon variations of density which may be considered infinitely small; but the beautiful method of least squares becomes inexact when applied to observations, whose errors are so great that their squares become large quantities, as well as the errors themselves.

92. M. Despretz performed his experiments in two different ways:† one, the method of Deluc, by employing a water thermometer; the other, a modification of the method of Tralles and Hope, by observing thermometers placed at different levels in the same vessel of water, the particles of which arrange themselves in strata according to their densities. To this method the objection has been urged, that it depends upon motion to be produced by the mechanical action of forces too feeble near the maximum to overcome the resistance opposed by the cohesion of the particles of water. And this objection is sustained by the discrepancy of the results; thus, Hope obtained $3^{\circ}.33$, $3^{\circ}.88$, and $4^{\circ}.16$; and Rumford, $4^{\circ}.38$ and $3^{\circ}.47$. Hållstrom rejects this method, as rather calculated to show the existence of a maximum several degrees above the zero point than to determine the precise degree with accuracy. He however remarks, that the mean $3^{\circ}.88$ of the observations is approximatively exact; and that, if a great many observations be made by different persons, a probable compensation of their errors would take place, and a mean result of considerable accuracy would be obtained. M. Despretz endeavors to overcome the objection mentioned, by suspending the vessel of water, and causing a vibratory motion of its particles by repeated gentle tapping with a stick; he thus obtains the mean result $3^{\circ}.987$; which, while it serves to confirm the determination $4^{\circ}.000$ of this first method, yet does not, in my opinion, prove that he has succeeded in doing away entirely with the objection to this hydrostatical method of Hope and Tralles; for his result is but the mean of observations whose errors compensate each other. This is proved by the curves, which otherwise should intersect nearly or exactly in a single point.

* Ann. de Chim. et de Phys., t. 28.

† See Ann. de Chim. et de Phys., t. 70, p. 1.

But it is to the observations of M. Despretz, made according to the method of Deluc, and which he has discussed by a very ingenious, graphic method, as well as by means of Lagrange's formula for interpolation by logarithms, that I would give the preference over all others. The method of Deluc, as it is the simplest, so also does it appear to be the most accurate; and the objections of Hällstrom are not, in my opinion, sufficient to show that its results are uncertain. The error of capillarity may be considered a constant, which is not a factor of the variations of volume by temperature, and which therefore disappears by differentiation from the equation of the maximum value of the density. And this constant might be rendered almost nothing, and certainly inappreciable in the observations themselves, by experimenting with tubes of greater diameter and proportionally larger bulbs. The graphic method of M. Despretz consists in representing the apparent dilatation of water by a curve of which the ordinates are the observations and the corresponding temperatures the abscissas. To this curve he draws a tangent parallel to the straight line which represents the dilatation of the glass of which the thermometer is constructed. Then it is evident that the abscissa of the point of tangency will represent the temperature of maximum density. If the law of the dilatation of water was known and expressed by a formula of perfect rigor, nothing would be easier than to determine this point of tangency with the utmost degree of exactness; for it would be merely requisite to make the differential coefficient of the curve equal to the coefficient of dilatation of the glass, and eliminate the corresponding value of x . In the absence of such knowledge, M. Despretz determines the point by regarding the curve as a parabola, from which it does not differ sensibly for a considerable extent on either side of that point; and he then avails himself of the property, that a diameter bisecting chords parallel to a tangent, cuts the parabola in the point of tangency. A member of the committee of the Academy, charged with the examination of the paper of M. Despretz, having informed him that they would have attached greater value to his researches if they had been discussed analytically, he undertook to calculate them by Lagrange's formula of interpolation

$$y_x = Xy + X_1y_1 + X_2y_2 + X_3y_3 + X_4y_4 + \text{etc.} \quad (32),$$

and obtained results exactly accordant with those of his graphic method.* In this formula

$$X = \frac{(x - a_1)(x - a_2) \dots (x - a_n)}{(a - a_1)(a - a_2) \dots (a - a_n)};$$

$$X_1 = \frac{(x - a)(x - a_2) \dots (x - a_n)}{(a_1 - a)(a_1 - a_2) \dots (a_1 - a_n)}; \quad (33).$$

$$X_n = \frac{(x - a)(x - a_1) \dots (x - a_{n-1})}{(a_n - a)(a_n - a_1) \dots (a_n - a_{n-1})}.$$

* See Ann. de Chim. et de Phys., t. 73, p. 296.

The manner in which M. Despretz has applied the method of curves to the results of each of his two methods of observation, constitutes, in my opinion, one of the chief excellences of his valuable memoir. And although the rigor of analysis entitles it to the highest regard, and renders it indispensable in the determination of the constants of nature, yet graphic methods possess peculiar advantages in physical inquiries, which the symbols of analysis never present; the one calls in the aid of the eye and the judgment, the other addresses itself to the mind, in the language of abstract relations of number.

As I have presumed to dissent from the views of the committee of the Academy with regard to the value of graphic methods, I may be permitted to cite high authority to sustain me. No one, who will take the pains to read the valuable paper of Sir John Herschel on the orbits of *double stars*,* can fail to admire the example presented by that memoir of the use of graphic methods. He there shows that the graphic process often determines *mean* results more accurately than formulas of interpolation; that it eliminates errors from the very observations themselves, correcting particular discrepancies by the general law of the whole mass of observations; and that, to use his own language, "in following the graphic process we have a conviction, almost approaching to moral certainty, that we cannot be misled." There is but one of our analytical methods at all analogous to this in its advantages, that of the least squares, which depends upon the principle that small errors are more probable than large ones; and, therefore, that, in the most probable observations, the errors do not compensate, but the sum of their squares is a minimum.

When the mean curve is not of any known form, it becomes difficult to discuss its properties; but for a limited arc, if free from singular points, it is proved, by the theory of osculations, that we may assume the curve to be identical with a parabola which coincides with it so nearly that the difference is inappreciable. It is thus, that the orbits of the planets are assumed to be conic sections, notwithstanding the discrepancies presented by perturbations. And this is equivalent to the analytical method of representing phenomena by formulæ, such as that employed by Biot, and all who have since attempted to discuss analytically observations of the law of dilatation, and of the temperature of the maximum density of water.† The method of M. Despretz, of determining the point of tangency by the bisection of parallel chords, is certainly accurate, for it is nearly equivalent to the familiar and general mode of determining the equation of the tangent to be a curve, by supposing a secant to vary until the points of secancy coincide; and, as the equation

$$y = a + bt + ct^2 + dt^3 + et^4 \dots + pt^n \dots \dots (35),$$

is the general equation of a parabola of the *n*th order, it follows that, by using the method of Despretz, which assumes the curve of dilatation to be the common parabola, whose equation is

$$y = a + bt + ct^2 \dots \dots \dots (36),$$

* See Trans. Astr. Sec., vol. v, p. 1.

† See Biot, *Traité de Physique*, t. I. p. 210.

we simply omit to take account of the terms of the third order in the formula

$$y = a + bt + ct^2 + dt^3 - - - - - (37),$$

which Biot has shown to represent the law of dilatation of liquids with accuracy, and which is the equation of the parabola of the third order.

Moreover, in judging of the exactness of our analytical methods, it should be borne in mind that the problem of interpolation is indeterminate, unless we know the law of the phenomena. For it consists in finding a function which shall have several given successive values for the corresponding values of the independent variable, and these conditions are fulfilled by many different functions, as is shown by the possibility of drawing various curves through a given number of points, and also in a very elegant manner by Lagrange's formula of interpolation. The numerator of the expression for the value of X of equations (33)

$$(x - a_1) (x - a_2) - - - (x - a_n)$$

is not the only function which vanishes when x becomes equal to $a_1, a_2, \dots a_n$. Lagrange has given the formula

$$u = A \sin. \frac{\pi x}{a} + A_1 \sin. \frac{2 \pi x}{a} + A_2 \sin. \frac{3 \pi x}{a} + \text{etc.},$$

as one which becomes 0, for each of the values x of the series $a, 2a, 3a, \&c.$, and which may serve for the interpolation of periodical functions. And the expression

$$X = \frac{\sin. m (x - a_1) \sin. n (x - a_2) - - - \sin. k (x - a_n)}{\sin. m (a - a_1) \sin. n (a - a_2) - - - \sin. k (a - a_n)}$$

is one which serves for any values of m, n , and k .

Similar functions may likewise be obtained for the values $X_1, X_2, \&c.$, of the equation

$$X_n = \frac{\sin. \alpha (x - a) \sin. \beta (x - a_1) - - - \sin. \phi (x - a_{n-1})}{\sin. \alpha (a_n - a) \sin. \beta (a_n - a_1) - - - \sin. \phi (a_n - a_{n-1})}$$

Hence it follows, that neither graphic nor analytical methods can give temperatures of maximum density with rigid exactness, so long as we are ignorant of the exact nature of the physical laws of the dilatation of liquids, though we can obtain values with all requisite approximative accuracy.

93. I have felt an interest in this matter sufficient to have induced me to apply the method of least squares, which Hällstrom seems to consider the only admissible one, to the experiments of M. Despretz. I thus obtain $4^{\circ}.223$, instead of 4° , as the probable determination; and this differs but $0^{\circ}.123$ from the mean which Hällstrom has deduced from the mass of observations made by different persons. The method I have followed is given in the next chapter.

New analytical discussion of the observations of M. Despretz.

94. As the method of least squares loses its advantage, and becomes inaccurate, when any of the extreme errors of calculation are very great, by giving to these errors an influence proportional to their squares,* and as the numerical calculations become very long and tedious when the method is applied directly to a large number of results, I have so combined the data of each set of the experiments of M. Despretz as to obtain mean equations, from which I then determine the temperature of maximum density of water by differentiation and the use of least squares. By following this method, I greatly abridge the labor of calculation, and the result is more accurate than if obtained directly from the observations themselves. Any great error is exposed, and that observation or set of observations may be rejected, or their probable error may be computed, and the corresponding correction applied; I prefer to reject them.

In the method I employ to obtain the unknown constant coefficient of Biot's formula, (37,) the mean value of a is given for each experiment by six determinations, that of b by two, and c by one only. Thus, greater accuracy is obtained where most required, and errors of observation are rendered apparent, particularly in the value of a , by discordant results.

Logarithmic computation becomes inaccurate when the numbers are very large. I have therefore found it necessary to employ the laborious method of actually performing all the multiplications and divisions. To avoid those accidental errors to which such arithmetical operations are peculiarly liable, the calculations were also made at my request by my brother; thus, mistakes were detected and corrected by differences in our calculations; nor have I failed to test even the accordant results by the approximative verifications which logarithms afford. Such care, in my opinion, should always be bestowed on determinations of the constants of Nature.

95. The formulas I have employed are usually contained in the works which treat of the calculus of finite differences,† and were first given, I believe, by Laplace.

$$\left. \begin{aligned} v &= at + bt^2 + ct^3 + \text{etc.} \\ v_1 &= at_1 + bt_1^2 + ct_1^3 + \text{etc.} \\ v_2 &= at_2 + bt_2^2 + ct_2^3 + \text{etc.} \\ v_3 &= at_3 + bt_3^2 + ct_3^3 + \text{etc.} \end{aligned} \right\} \dots \dots (38);$$

then if we put

$$\frac{v - v_1}{t - t_1} = f(v); \quad \frac{v_1 - v_2}{t_1 - t_2} = f(v_1); \quad \frac{v_2 - v_3}{t_2 - t_3} = f(v_2); \text{ etc.}$$

* See Bowditch's Notes to Laplace, *Mécanique Céleste*, vol. ii, p. 434.

† See Lacroix, *Calc. Diff.*, vol. 3, p. 32, 4to; Paris, 1819.

we shall have

$$\left. \begin{aligned} f(v) &= a + b(t + t_1) + c(t^2 + t t_1 + t_1^2) + \text{etc.} \\ f(v_1) &= a + b(t_1 + t_2) + c(t_1^2 + t_1 t_2 + t_2^2) + \text{etc.} \\ f(v_2) &= a + b(t_2 + t_3) + c(t_2^2 + t_2 t_3 + t_3^2) + \text{etc.} \end{aligned} \right\} \quad (39),$$

and analogously subtracting each of the two last equations from that which precedes, and dividing by the factor of the first term, we obtain

$$\left. \begin{aligned} f_2(v) &= b + c(t + t_1 + t_2) + \text{etc.} \\ f_2(v_1) &= b + c(t_1 + t_2 + t_3) + \text{etc.} \end{aligned} \right\} \quad (40).$$

From which, lastly :

$$f_3(v) = c \quad (41).$$

Hence it is evident that we shall obtain from four equations of condition (38) one value of c , two values of b , and six values of a ; for each of the values of b gives a value of a in the equations (39.) And since three equations of condition determine the values of three unknown quantities, our fourth equation serves as a test upon the accuracy of the observations, and will give very discordant values of the coefficients, if they are not free from considerable error. Thus, in the third experiment, they lead to two widely different values for b , or, if equal values are assigned, to absurdity; I have therefore rejected it entirely. It is not unlikely that I may have copied the observations incorrectly in my notes from the memoir of M. Despretz, which is not now within my reach, or that they are printed incorrectly.

96. The following are the observations of M. Despretz, which I have submitted to calculation, and arranged for brevity in tabular form. They are those to which he has himself applied Lagrange's formula of interpolation.

Experiment I.		Experiment II.		Experiment III.		Experiment IV.	
Temp.	Volume.	Temp.	Volume.	Temp.	Volume.	Temp.	Volume.
° C.		° C.		° C.		° C.	
7.48	92759.08	7.18	92757.39	5.91	92745.69	6.33	92754.46
5.90	92753.29	5.69	92752.60	4.73	92743.23	5.68	92752.72
3.74	92750.83	4.04	92750.64	3.23	92743.33	5.21	92751.86
2.17	92753.12	2.59	92752.07	1.86	92746.11	3.87	92750.84

The numbers in the vertical columns of volume express divisions of the graduated scale contained both in the reservoir and the tube; to which the correction of dilatation for the particular glass has been applied, so that the volumes are absolute. A second tube gave the following analogous results :

Experiment V.		Experiment VI.		Experiment VII.		Experiment VIII.	
Temp.	Volume.	Temp.	Volume.	Temp.	Volume.	Temp.	Volume.
° C.		° C.		° C.		° C.	
5.91	61842.54	7.18	61841.89	7.48	61843.01	7.77	61857.52
4.93	61841.00	5.69	61838.64	5.90	61839.82	6.05	61852.76
3.23	61841.01	4.04	61837.39	3.74	61837.52	4.27	61850.75
1.86	61842.77	2.59	61838.30	2.47	61839.04	1.41	61854.34

It appears that the temperatures of experiments Nos. 1, 2, 3, and 7, 6, 5, are identical; but while the volumes of No. 5 do not differ, except by a few units, from those of No. 6 and No. 7, those of No. 3 vary greatly from the volumes of No. 1 and No. 2; this also proves the propriety of rejecting No. 3 as incorrect. To the identity I have mentioned, there is one exception—the last temperature of No. 1 is $2^{\circ}17$, while that of No. 7 is $2^{\circ}47$. The values of a , which I have obtained for the observations of No. 1, give somewhat discordant results; while those of No. 7 accord very closely. I therefore tried the effect of supposing 2.17 to have been, by an error of printing or copying, substituted for 2.47, but the discrepancy became much greater, and affected the values of b to an extent which rendered it necessary to abandon the hypothesis. This fact serves to show the accuracy of the method employed, as well as of the observations themselves; for the error of three-tenths of a degree rendered it impossible to obtain values at all alike, even for the coefficient of the second power of the temperature.

97. The calculations are too long to be given in full in this paper, nor would any one desire to follow them; their results may, however, be embodied in tables, which any one may test by particular examples, who is so disposed. To render the numbers smaller, I subtract each temperature from 4° ; which cannot affect the result of the maximum density, as is evident from the fact that it is equivalent to a simple change of the origin of co-ordinates. By substituting the numerical values in the formulas of article 95, I obtain:

No.	$f(v)$	$f(v_1)$	$f(v_2)$	$f_2(v)$	$f_2(v_1)$	$f_3(v)$
1	4.3037974	1.1342590	-1.4585987	0.8501439	0.6951091	0.02919676
2	3.2147651	1.1878788	-0.986217	0.6455052	0.6948697	0.0107549
3	2.0423729	-0.0333333	-1.1029197	0.7745172	0.3726788	0.9921688
4	0.2670707	0.1829787	0.7611940	0.0750821	-0.3194559	0.1603813
5	1.3050847	-0.0066666	-1.2846715	0.4894594	0.4452978	0.01090401
6	0.7575757	-0.6275862	0.78213507	0.4468264	0.4489558	0.0014291
7	2.0189873	1.0648141	0.8491620	0.2551265	0.0628723	0.0383741
8	1.1292134	1.2552447	0.2500000	0.5138918	0.5014984	0.0072054

And from these I deduce the coefficients a and b , by similar substitution.

No. 1.	No. 2.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
<i>b.</i>	<i>b.</i>	<i>b.</i>	<i>b.</i>	<i>b.</i>	<i>b.</i>	<i>b.</i>
0.70065687	0.69831176	-0.7620983	0.4690689	0.44636909	0.05865121	0.5119463
<i>a.</i>	<i>a.</i>	<i>a.</i>	<i>a.</i>	<i>a.</i>	<i>a.</i>	<i>a.</i>
-0.1175600	0.0112790	1.3719340	0.0059497	-0.0188234	0.84645848	-0.0237511
-0.1207432	0.0112618	1.3719449	0.0059495	-0.0188234	0.84645861	-0.0237082
-0.1078802	-0.0087375	1.3719635	0.0059504	-0.0251579	0.84645791	-0.0237304
<i>b.</i>	<i>b.</i>	<i>b.</i>	<i>b.</i>	<i>b.</i>	<i>b.</i>	<i>b.</i>
0.70065648	0.69831127	-0.7621079	0.4690682	0.4463691	0.05865118	0.5119463
-0.1175570	0.0112398	1.3719726	0.0059497	-0.0188236	0.84645790	-0.0237511
-0.1207432	0.0112629	1.3719819	0.0059356	-0.0188234	0.84645798	-0.0237082
-0.1079105	-0.0085583	1.3719738	0.0059484	-0.0251579	0.84645860	-0.0237304
0.700656675	0.698311525	-0.7621032	0.46906855	0.446369095	0.58651195	0.5119463
-0.1153990	0.00463128	1.3719618	0.0059472	-0.0209349	0.84645825	-0.0237299

The two last horizontal columns contain the mean values of the numbers above.

By differentiation, the formula (37) gives

$$\frac{dv}{dt} = a + 2bt + 3ct^2 \quad (42);$$

which, for the maximum, becomes equal to zero. Hence, by substitution and reduction, after passing again to the primitive origin of abscissas, we obtain in degrees centigrade from

$$\left. \begin{aligned} \text{No. 1, } 0 &= 6.89129888 - 2.10203559 t + 0.08759028 t^2; \\ 2, 0 &= 5.07488608 - 1.1385049 t - 0.0322647 t^2; \\ 4, 0 &= 2.9734386 - 2.3249448 t + 0.4811439 t^2; \\ 5, 0 &= 4.28188808 - 1.19983334 t + 0.03271203 t^2; \\ 6, 0 &= 3.61861466 - 0.92703659 t + 0.0042873 t^2; \\ 7, 0 &= 7.38051065 - 2.0940023 t + 0.1151223 t^2; \\ 8, 0 &= 3.7259813 - 0.850963 t - 0.0216162 t^2; \end{aligned} \right\} (43).$$

And these are the *mean* equations of condition to which (as stated in art. 94) the method of least squares is to be applied, instead of using the actual observations themselves.

98. The method of least squares gives:

$$\left. \begin{aligned} \text{No. 1, } 0 &= -14.485755070971392 + 4.418545213488288 t - 0.184596484695218 t^2; \\ 2, 0 &= -5.777694549121792 + 1.29619340732401 t + 0.03673351904703 t^2; \\ 5, 0 &= -5.137552076532587 + 1.4386008690995556 t - 0.0392489842130802 t^2; \\ 6, 0 &= -3.3545881949244094 + 0.8593968391988281 t - 0.003974483972307 t^2; \\ 7, 0 &= -15.45480627627449 + 4.3849081620529 t - 0.24106636098129 t^2; \\ 8, 0 &= -3.1706722249919 + 0.724084420669 t - 0.0183945864006 t^2; \end{aligned} \right\}$$

And from these we have the final equation of the second degree

$$0 = -47.381068828942317 + 13.1217289118325818 t - 0.4505473812254652 t^2;$$

From which I deduce $4^{\circ}.223$ as the value of t , or the temperature of the maximum density of water.

This differs two-tenths of a degree from the determination of M. Despretz, a quantity which but serves to show the accuracy of his experiments, and of the calculations by the method he employed. Since $4^{\circ}.223$ centigrade are equivalent to $39^{\circ}.601$ Fahrenheit, and it is impossible to read to the thousandth of a degree, I conclude that $39^{\circ}.6$ Fahrenheit is the temperature of the maximum density given by the most exact researches. For ordinary practical purposes, we may employ $39^{\circ}.5$ Fahrenheit, or 4° centigrade. In the final calculations, I have taken no account of No. 4, by reason of the great probable error by which the mean equation is effected, which renders it proper that it should be discarded.

It is interesting to know that the temperature $39^{\circ}.4$ Fahrenheit, adopted by the late Mr. Hassler for the construction of the standard weights and measures of the United States, differs but two-tenths of a degree from the result of the preceding calculation; a difference which could not produce any appreciable errors in those standards.

On the dilatation of mixtures of alcohol and water.

99. On this subject, perhaps the most difficult and extensive connected with the present inquiry, my researches have not led me to many important results, nor assumed a shape sufficiently definite to be included in this report. Neither have I made any experiments; because, to be properly made, they should be definite questions propounded to nature as the witness, with particular objects in view. Otherwise, experiments become a mere waste of time and money. It is but a few days since I have received from France and Germany the papers which contain the results of similar researches made for the Governments of those countries; the labors of Gilpin and Blagden, for the British Government, have been in my possession from the time nearly at which I commenced these investigations in June last; and I have also collected from the various journals and transactions of scientific societies much valuable original matter. To discuss this mass of information thoroughly, requires more time than I have yet been able to command; but, as I devote a considerable portion of my labor to this branch of the inquiry, I hope at an early day to be able to report the complete and final results. The method of discussion I follow is at first graphical, that the eye may aid in seizing the laws of the phenomena; subsequently, analysis serves to give more exact determinations.

An interesting result at which I arrived, soon after I commenced my investigations, is presented by the fact that, for all practical purposes, liquors containing more than thirty per cent. of alcohol may be considered to expand uniformly for equal increments of temperature of the mercurial thermometer. This law becomes more exact the greater the per cent. of alcohol contained, and the error is within the limits of errors of observation, if that per cent. exceed ninety. I was first led to this conclusion by the consideration of the circumstance that the first differences are nearly constant, and it is fully verified by the graphic process. A glance at plate II will be sufficient to convince any one of the truth of this law; for it shows that the parabola, which represents the dilatation of very dilute aqueous solutions of alcohol, gradually passes into a straight line; I have drawn the

curves on a large scale, of which plate II is merely a reduced copy. The researches of Gilpin and Blagden furnish the data which I have employed in this determination.

Within a few days, I have found, in reading the report of Tralles to the Prussian Government, that he confirms the law I have just given, as far as it is applicable to absolute alcohol; for, in a note by Gilbert,* it is stated that Tralles "found, from experiments made with absolute alcohol, that between -15° and $+15^{\circ}$ Fahrenheit, it expands as uniformly by heat as mercury or air. The opinion hitherto entertained, that alcohol obeys a different law of dilatation, is therefore to be attributed to the water with which it is generally mixed."

In plate II, figs. 5, 6, and 7, I have drawn tangent lines, to enable the eye to judge of the curvature. In fig. 8, the tangent becomes coincident with the curve itself, which therefore has passed into a straight line.

I shall defer further remarks upon the subject of dilatation to a future occasion, when I shall have fully investigated the subject; and I feel that they may now be properly excluded, as this report has attained a length much beyond what I had supposed would be necessary. I will simply add, that I propose to make a series of experiments of verification with thermometers constructed of different proportions of alcohol and water, a method which I regard as both the simplest and most exact.

On the different proofs of spirits.

100. It appears that, in nearly all countries, there is established in trade a system of "*proofs*," or commercial conventional strengths, at which spirituous liquors are bought and sold. And were not these "*proofs*" interfered with and modified by particular legislation, it is not unlikely that there would arise uniform commercial standards throughout the world. For exportation, it is always desirable that liquors should be as strong as possible, to avoid paying freight on mere water of dilution; and water, which may be found any where, should be added rather by the consumer than the producer; hence, each kind of spirits will, if trade be left to take its natural course, be furnished to foreign markets of but one degree of strength, which will be the maximum attainable without injury to the quality. Of some varieties of ardent spirits, as for instance, cognac brandy and the *Kirschwasser* (cherry brandy) of the Black Forest, the value depends upon the flavor, and the strength is a subordinate matter; nor could such liquors generally be highly rectified without injury to their flavor. But, as a general rule, the value of a liquor depends upon and is proportional to the strength, or the per cent. of alcohol it contains.

101. The necessity of proving in trade the strength of ardent spirits, that the buyer may know how much water he is bargaining for, has led to the use of hydrometers; and I cannot better illustrate the value of this little instrument than by translating a passage from the writings of the Baron Charles Dupin: "The Spaniards, whose strong wines are very well suited for distillation, endeavored to compete with us in the manufacture of brandy. But, neglecting to measure the degree of concentration with the hydrometer, they merely let fall from a certain height a drop of oil into

*See Gilbert's *Annalen der Physik*, Jahrg. 1811, St. 8, S. 364.

the brandy. The deeper this drop sank, the stronger they concluded the liquor to be. But so rough a method constantly led them into error. They therefore furnished to the foreign markets brandies of very unequal degrees of strength, which gave their production a very bad reputation, and they were even compelled to sell to us at reduced prices. Then, with our hydrometers we easily reduced their brandies to the proper degree of strength, and sold them for the same prices as our own. This commerce, with the north of Europe alone, caused us to gain four millions of francs yearly before the revolution. At present, the Spaniards, having learned to use hydrometers, no longer permit us to enjoy this benefit. Hence, it is easily seen what important advantages a very simple little instrument may give to certain nations in commerce and wealth. Such is the practical value of science.”*

102. It seems to me that the proper policy to be adopted by Governments, in levying duties on ardent spirits, is so to frame their laws and regulations that they may be adapted to, and not in conflict with, the system of strengths which would obtain in commerce if there were no duties to be paid. By so doing, commerce may be facilitated, which otherwise is subjected to considerable inconvenience. Again, as the tastes and habits of the same country vary with time, it appears to me that no one system of commercial proofs can be considered fixed; and therefore legislation should be general, or independent of particular proofs and of the hydrometer used, and so devised that any commercial change may not be hindered, nor require the existing laws to be modified. This can be done by levying duty on the alcohol contained, without regard to the water, which is valueless; nor do I see how it could be otherwise readily accomplished.

103. There seems to be but one degree of proof, or strength, which is common to nearly all countries except England; this is, the “first proof” of the United States, “*die holländische Probe*” of Germany, and the “*preuve d’Hollande*” of France. It marks, 19° Cartier, ten per cent. below hydrometer proof of Dycas, and 50 per cent. by volume of the alcoholometer of M. Gay Lussac; and it is therefore composed by measure of equal parts of alcohol and water. When spirits of this degree of strength is briskly agitated in a flask, a series of little bubbles form at the surface, and it is then said to give a “head,” or to be of “the Holland proof,” or is simply called in general commerce proof spirit.

104. In France there are found in commerce other degrees of strength, which are all referred to proof spirit (*preuve d’Hollande*) as a type. These are called “*esprit trois-cinq*,” (spirit three-five;) “*esprit trois-six*,” (spirit three-six;) “*esprit trois-sept*,” (spirit three-seven;) and so on. These terms signify that three volumes diluted with water to five, six, seven, etc., volumes, will then be of the strength of Holland proof, which is the liquor of consumption. But the duties, as I have before stated, are levied by the French Government on the proportion of alcohol by volume contained in any spirit, without regard to its commercial name.

105. In England, the laws of the excise seem to have taken precedence,

* See Géom. et Méc. des Arts et Métiers et des Beaux Arts; par M. le Baron Ch. Dupin t. iii, Dynamie, 7e Leçon.

and to have counteracted the influences of general commerce entirely. In the language of Dr. Ure,* "the inquisitorial *regime* imposed by law upon our distilleries might lead a stranger to suppose that our legislators were desirous of repressing, by every species of annoyance, the fabrication of the fiery liquid which infuriates and demoralizes the lower population of these islands. But, alas ! credit can be given them for no such moral or philanthropic motive. The necessity of the exchequer to raise a great revenue, created by the wasteful expenditures of the State on the one hand, and the efforts of fraudulent ingenuity on the other, to evade the payment of the high duties imposed, are the true origin of that *regime*. Examinations in distilleries are constantly making by the officers of the excise. There is a survey at 6 o'clock in the morning, when the officers take their accounts and gauges, and make calculations which occupy several hours. At 10 o'clock they again survey, going over the whole premises, where they continue a considerable time, frequently till the succeeding officer comes on duty. At 2 in the afternoon another survey takes place, but not by the same people. At 6 in the evening the survey is repeated ; at 10 there comes another survey, by an officer who had not been engaged in any of the previous surveys of that day. He is not relieved until 6 the next morning. In addition to these regular inspections, the distilleries are subject to frequent and uncertain visits from the surveyor and surveyor general. We are never," says Mr. Smith, the eminent distiller of White Chapel, "out of their hands." Such is the excise system of Great Britain. And it was the remembrance of the hardships and severities to which the British excise laws and their violations had led, which gave rise, at an early period of the history of our Government, among the Scotch and Irish settlers of Western Pennsylvania, to the insurrection, which is familiarly known as that of the "whiskey boys," in consequence of an act establishing a system of excise with relation to domestic distilled spirits. The policy of Great Britain seems to be regulated rather by the excise than the customs. Hence, her complicated, artificial, and very imperfect system of "over proofs" and "under proofs," is peculiarly her own. Nor has it been imitated, except to a certain limited extent, in our country, in consequence of the adoption of Dycas's Liverpool hydrometer as the standard of the United States.

106. In Great Britain, duty is charged on "*Sikes's hydrometer proof spirit*;" and if a liquor be not of that degree of strength, then, by act of Parliament, a calculation is to be made by Sikes's tables and hydrometer, to obtain the "over proof" or "under proof," which is "the decimal multiplier by which the gauged content of a cask is to be multiplied," and thus increased or diminished so as to reduce it to hydrometer proof spirit ; upon which calculated volume the duty is then to be paid. To determine what constitutes Sikes's hydrometer proof spirit, we have the definition of the act of Parliament, that at 51 degrees of Fahrenheit it weighs twelve-thirtieths of the weight of an equal bulk of water. In decimal fractions $12.13 = 0.923007$, which is therefore the specific gravity, if water be taken at the same temperature as unity. This specific gravity, reduced to 59° Fahrenheit, becomes 0.920 nearly ; which, by the table of Marozeaut for

* See Dictionary of Arts and Manufactures, p. 403 ; London, 1840.

† See Encyclopedia of Chemistry, by Messrs. Booth and Boyé—art. Alcoholometer, page 96 ; Philadelphia, 1844.

densities corresponding to the indications of Gay Lussac's alcoholometer, gives 58 per cent., by volume, as the proportion of alcohol in Sikes's hydrometer proof spirit.

107. In the United States, Dycas's Liverpool hydrometer seems to have come into use in the following manner: It was employed in the States at the time of the formation of the Federal Union, and was therefore adopted by our Government by act of Congress approved August 10, 1790. In that same act I find spirits divided into six classes,* namely: 1st, "distilled spirit of more than ten per cent. below proof, according to Dycas's hydrometer;" 2d, "if more than five and not more than ten per cent. below proof, according to the same hydrometer;" 3d, "if of proof, and not more than five per cent. below proof, according to the same hydrometer;" 4th, "if above proof, but not exceeding twenty per cent., according to the same hydrometer;" 5th, "if of more than twenty and not more than forty per cent. above proof, according to the same hydrometer;" 6th, "if more than forty per cent. above proof, according to the same hydrometer." By act of Congress, approved March 3, 1791, it is enacted† that these six "several kinds of proof shall be distinguished, corresponding with the order in which they are mentioned, by the words "first proof," "second proof," "third proof," "fourth proof," "fifth proof," "sixth proof;" "and that it be the duty of the Secretary of the Treasury to provide and furnish to the officers of inspection and of the customs proper instruments for ascertaining the said several proofs." This system, thus established by law, has not since been disturbed; and although the Secretary of the Treasury is, by act of Congress approved January 10, 1825, "authorized to adopt and substitute such hydrometer as he may deem best calculated to promote the public interest, in lieu of that that now prescribed by law, for the purpose of ascertaining the proof of liquor," no change has taken place. And this may perhaps be owing chiefly to the fact, that no appropriation has ever been made to enable the Secretary of the Treasury to carry this law into effect, by causing proper investigations to be made by competent persons. At the time, when Dycas's hydrometer was adopted by our Government, it was perhaps the most perfect instrument known; but this superiority it has long since lost, and it is now as far inferior to the centesimal alcoholometer of M. Gay Lussac as it was then superior to the instrument of Clarke, which it superseded. I do not consider the hydrometer of Sikes more perfect than that of Dycas; and, indeed, it is more uncertain, if constructed by ordinary workmen, in consequence of the fact that the weights are immersed.

108. The language "ten per cent. *above* proof," "twenty, thirty, forty, etc., per cent. *above* or *below* proof," for Dycas's hydrometer, is not, as would be generally supposed, synonymous with the corresponding language, "ten per cent. *over* or *under* proof," for Sikes's hydrometer. It varies in signification, not only because the proofs of these hydrometers do not correspond to the same strength of spirits, but also materially in itself. The "over proof" and "under proof" of Sikes is the quantity per cent. by which the gauged content of a cask is to be multiplied, to reduce it to the equivalent quantity of hydrometer proof spirit. But the "per cent. *above* or *below* proof" of Dycas is the quantity of water which

* See Laws of the United States, vol. 2, page 176, chap. 66, sec. 1.

† See Ibid, vol. 2, page 215, chap. 89, sec. 37.

may be added to or subtracted from the liquor, to reduce it to liquor of the strength of proof. Now, these quantities are not the same; for when alcohol and water are mixed, a molecular attraction or condensation takes place, which renders the volume of the mixture considerably less than the sum of the volumes of the liquids mixed; and this condensation may amount to more than three and a half per cent.

109. Although the above-described system of proofs has been for more than fifty years established by law for levying duties on foreign spirits imported into the United States, it does not appear to be in harmony with the mercantile system, and has therefore been rejected in commerce. In New York, a single proof has been by law adopted, and duties are laid on strengths shown directly by Southworth's hydrometer in per cent. above and below this proof. In Boston, a hydrometer has been brought forward by Messrs. Tucker and Dwelle, apparently copied from that of Sikes, but which is based upon proof spirit of "the American mercantile standard," which seems to be the first proof of the United States, or Holland proof of Europe. In Philadelphia, by law of the State of Pennsylvania, passed April 15, 1835, it is enacted, "that if the liquor shall be hydrometer proof, (by Dycas's hydrometer,) it shall be marked as liquor of the fourth proof; if five degrees below hydrometer proof, it shall be marked as liquor of the third proof; if the liquor shall be ten degrees below hydrometer proof, it shall be marked as of the second proof; if it shall be fifteen degrees below hydrometer proof, it shall be marked as of the first proof." This standard is evidently inferior to that of the United States. In Baltimore, I am informed that, by act of the Legislature of Maryland, the gaugers are required to mark on each cask its contents reduced to "first proof" spirit, (United States standard,) to certify the same to the vender, and to give no other information. Hence it would seem that, with the exception of "first proof" spirit, the standards established by law are arbitrary, and that they might even be abolished, and a different and simpler system adopted, without inconvenience in commerce, and with advantage in the revenue. Before recommending, however, any particular change in the existing regulations, it is, in my opinion, expedient to consult the views and wishes of merchants who are well informed upon these subjects, and who have imported large quantities of spirits from foreign countries.

Experiments of comparison of several of the hydrometers used for spirits.

110. The temperatures were observed by three different thermometers, one of the centigrade scale, made by Greiner, of Berlin; another by Bate, the hydrometer maker to the revenue of Great Britain; and a third by Fisher, of Philadelphia; the two last belonging to the hydrometers of Sikes and Dycas used in the experiments. To verify their zero points, the thermometers were placed at the same time in pure melting ice, and were found to be stationary at the following points: Greiner, at $+ 1^{\circ}$ centigrade; Bate, at $34^{\circ}.5$ Fahrenheit; Fisher, at 33° Fahrenheit. The errors of the zero points are therefore, respectively, $+ 1^{\circ}$ centigrade, $2^{\circ}.5$ Fahrenheit, and 1° Fahrenheit. Two sets of observations were then made, one for a constant temperature varying the strength, and another for va-

riable temperatures and a constant degree of strength. The following are the observations, exactly as they were made.

111. The temperature being nearly constant, and the strength variable, descending :

Thermometer.			Hydrometers.							
Greiner.	Bate.	Fisher.	Gay Lussac. Collardeau.	G. Luss. Pixii.	Dycas. Fisher.	Sikes. Bate.	Beaum. Greiner.	Beaum. Pixii.	Beck.	Cartier.
° C.	° C.	° F.			°	°	°	°	°	°
22.7	72.8	72.7	—	—	246.9	29.2	33.	30.1	21.3	31.
22.5	72.3	72.3	71.	71.3	205.	41.5	28.7	27.	—	26.8
22.3	72.	72.	67.25	67.3	186.2	46.6	27.7	25.	15.6	25.
22.	71.7	71.5	64.1	64.6	173.5	50.58	25.2	24.	14.3	23.7
22.6	72.5	72.5	59.	59.5	150.9	57.9	23.1	22.	12.3	21.7
22.5	72.3	72.2	55.2	55.5	136.5	61.1	22.	20.5	11.2	20.3
22.5	72.3	72.5	49.5	*	115.6	67.2	20.2	19.	9.2	18.25
23.	73.7	73.7	42.5	*	93.3	73.6	18.3	17.25	7.2	15.25
23.	73.5	73.5	38.6	*	81.8	77.1	17.	16.2	6.2	

* So inclined, owing to want of symmetry of form, as to render reading impracticable.

These observations were made under the most favorable circumstances; for both the temperature and degree of strength were in a statical condition at the time of reading. In the following series, however, the temperature was in a dynamical condition, with but three exceptions.

112. The manner in which the influence of temperature was observed in these experiments was by enclosing the bell-glass, (a large one,) containing the alcoholic solution, in another much larger one, and then filling the intervening space first with hot water, and subsequently with melting ice. The temperature and the indications of the different hydrometers were read off before adding the hot water or the ice, when the whole was in a statical condition, and again after the mixture and the apparatus had acquired the temperature of the room. When the temperature of the liquor was in a dynamical state, it was impracticable to read all the hydrometers before the thermometer indicated a different degree; it was therefore not attempted; and greater accuracy was attained by reading several at intermediate temperatures. No observations were made until sufficient time had elapsed to allow an equilibrium to take place of the ascending and descending currents of different density, except in so far as they might be produced by the temperature of the room and of surrounding bodies.

Thermometers.			Hydrometers.							
Greiner.	Bate.	Fisher.	Gay Lussac. Collardeau.	Gay Lussac. Pixii.	Gay Lussac. Pixii.	Dycas. Fisher.	Sikes. Bate.	Beaumé. Greiner.	Beaumé. Pixii.	Beaumé. Heintz.
16° 8 C.	° F.	66° F.	87° 3	87° 3	86° 5	292° 3	16° 2	37° 3	33° 8	33° 4
27.8	81.7	84.	90.5	90.5	.....	312.	10.7	.....	.....	.....
.....	81.	81.7	89.8	89.8	.....	307.6	12.	39.	.....	.....
26.	80.	80.	89.4	89.4	.....	305.	12.6	.....	35.	34.3
.....	76.7	76.6	88.8	89.	88.2	302.4	13.3	38.3	34.8	34.
.....	76.	76.	88.5	88.8	.....	303.3	13.6	38.	34.5	34.
.....	75.	75.	88.6	88.6	.....	301.	13.8	38.	.....	.....
19.7	67.5	68.	87.2	87.1	86.6	291.	16.8	37.25	33.6	33.
1.	Scale warped so that it could not be used.	33.	82.	82.2	81.5	262.8	24.9	34.3	31.3	30.5
.....	.....	38.	83.	83.	.....	272.	22.7	35.	.....	.....
5.	.....	40.	83.4	83.5	.....	273.5	22.1	35.2	.....	.....
.....	.....	43.	83.9	84.	83.5	275.7	21.4	35.4	32.5	.....
8.	.....	46.	84.1	84.3	.....	277.3	20.9	35.5	33.	.....
11.	50.	50.2	85.	85.2	.....	282.1	19.2	36.	.....	.....
.....	59.	59.	85.7	86.	.....	284.5	18.7	36.2	.....	.....
17.	60.	60.	86.	86.2	85.3	285.5	18.2	36.3	.....	.....
17.	60.7	60.5	86.1	.....	.....	.....	.....	.....	33.5	32.8
20.	68.	67.5	87.	87.1	86.5	291.2	16.6	37.2	33.9	33.3

I have felt at a loss to account for the close accordance in these experiments of the indications of temperature given, respectively, by the thermometers of Bate and Fisher; and I feel inclined to suspect the observation of the zero point of Bate's thermometer, as stated in article 110, of inaccuracy. But I was not at the time aware of any error, if it occurred, as I now suppose it probably did. The centigrade thermometer of Greiner was a laboratory thermometer, not of sufficient sensibility to be read accurately within a quarter of a degree.

The alcoholometer of M. Gay Lussac, made by M. Collardeau, who is the hydrometer maker to the French Government, appears to be one which was manufactured several years ago; and it was procured, I believe, for the Treasury Department, by the late Mr. Hassler. I have recently imported another instrument of the same kind, and by the same maker, and I find them to agree perfectly in their indications. The two alcoholometers of Gay Lussac, which I have recorded as of the make of M. Pixii, are of very inferior workmanship; they are not marked with any name, and I attribute them to M. Pixii solely because I was told by the importer that they are of his manufacture, but I may not have been correctly informed.

The pesé-esprit of Beaumé, which I have set down as of the manufacture of M. Pixii, bears his name upon its scale.

113. To render the preceding comparative observations more distinct, I have reduced the indications of the hydrometers of Sikes, Dycas, and Gay Lussac, of the first series of experiments, to their equivalent per cent. by volume of absolute alcohol. Their discrepancy is thus rendered manifest.

Gay Lussac.	Dycas.	Sikes.	Gay Lussac.	Dycas.	Sikes.
.....	75.9	77.7	52.5	53.	53.
68.6	68.2	69.	46.7	47.4	47.
64.8	64.5	65.5	39.3	39.9	39.
61.7	61.8	62.9	35.3	36.1	35.
56.3	56.5	56.			

I do not think there can be any doubt which of these instruments is the most exact, for the high and well-earned reputation of M. Gay Lussac at once claims for his researches our credit, apart from the simplicity of his hydrometer, and its consequent perfection.

114. From the second series of observations, and the tables of M. Gay Lussac for mixing liquors, I derive the data for the following comparison of the reduced indications of the hydrometer of Gay Lussac and Dycas :

Gay Lussac.		Dycas.	Gay Lussac.		Dycas.	Gay Lussac.		Dycas.
Per cent. by vol.	Over proof.	Over proof.	Per cent. by vol.	Over proof.	Over proof.	Per cent. by vol.	Over proof.	Over proof.
86.16	51.5	50.6	86.16	54.5	50.7	86.06	54.3	51.5
86.76	55.6	51.5	85.81	53.9	49.7	86.4	54.9	51.8
86.4	54.9	51.	86.05	54.3	50.6	85.75	53.8	50.3
86.2	54.6	50.7	86.2	54.6	51.9	85.85	54.	50.3
86.25	54.6	50.7	86.35	54.9	51.7	85.9	54.2	50.
86.15	54.5	51.3	86.35	54.9	51.7	85.9	54.2	

It appears, therefore, that there is a discrepancy of these instruments for spirits of the strength used in the experiments of nearly 4 per cent. An equation for penetration or condensation would cause these "over proofs" to accord very closely, but such an equation is not admissible for Dycas's hydrometer.

115. In conclusion, I would add, that it seems to be desirable that a series of accurate chemical analyses should be made, with the view of determining the nature and quantities of vegetable extractive matter contained in the various distilled spirits of commerce, and the consequent influence exerted upon the density. The use of hydrometers assumes this influence to be inappreciable; but I do not find published experiments upon

which I can rely, though I doubt not such have been made by M. Gay Lussac and others.

Respectfully submitted, by

RICHARD S. McCULLOH.

Professor A. D. BACHE.

A.

PHILADELPHIA, *August 1, 1843.*

SIR : Agreeably to your request, made known to us through Doctor D. B. McGinley and Mr. T. Stewart, we have undertaken the analysis of the specimens of molasses sent to us by them, and have endeavored to devise a practical method of determining the quantities of crystallizable sugar contained in them. About to close our laboratory until the 1st of September, we offer you at present our results in regard to the specimens handed to us. But, in order to understand the difficulties attending the contrivance of a method for ascertaining the quantity of crystallizable sugar present, permit us to make the few following remarks :

Sirups and molasses contain at least two varieties of sugar, which we will distinguish by the names of crystallizable and uncrystallizable, or molasses sugar, (sometimes termed caramel.) The first may be obtained from its solution in solid form, either as an aggregation of small crystals, as in loaf sugar ; or in large crystals, as in sugar candy ; or more impure, as small colored and loose crystalline grains, constituting the different varieties of brown sugar. (All brown sugars may be refined into loaf sugar, if it otherwise pays the trouble in an economical point of view.) Molasses sugar, on the other hand, is soluble in water, in all proportions, and imparts therefore a richer sweetness to it ; nor can it be obtained in a solid state, excepting by evaporating its water at a higher temperature, when it forms a fused mass, which solidifies, on cooling, into a brown, hard, and glassy mass ; it again softens in the air by attracting moisture. These two varieties of sugar are ascertained to be entirely distinct in their composition and behaviour to tests. Very slight chemical causes will convert the former into the latter, such as heat, acids, alkalies, albuminous and other nitrogenized substances, such as are found in vegetable juices ; while the latter has never been restored to the former or crystallized state. Now, where the two are mingled together, as in most molasses and sirups, the viscid nature of the uncrystallizable sugar impedes the separation of the other in a crystalline state ; the presence of foreign matter, such as sacchulmine, gum, extractive matter, etc., forms an increased hinderance to the separation of crystallized sugar, its particles being prevented from uniting. In attempting the removal of these ingredients by chemical means, the reagents are very apt to convert the crystallizable sugar into molasses sugar—thus defeating the object in their separation. You will hence perceive the difficulties of contriving a practical process for the quantitative estimation of crystallizable sugar in molasses and sirups, which has not yet fully succeeded, notwithstanding the valuable prizes offered by governments and scientific bodies to effect this object.

It is also evident, from the preceding remarks, that their value, for the

purpose of extracting crystallizable sugar from them, depends not only on the actual amount of the latter in them, but also inversely on the amount of foreign substances; while, on the other hand, molasses, as such, improve in quality by the extraction of the crystallizable sugar, which, by separating, impair their transparency, while the purification which they undergo for its separation imparts to them a richer color and taste.

We subjoin the following table, as exhibiting the results of our experiments:

	New Orleans molasses.	Porto Rico molasses.	New Orleans molasses.	Porto Rico molasses.	Porto Rico molasses.	Porto Rico molasses.	Arecibo (P. R.) molasses.	Matanzas molasses.	Matanzas sirup.	Matanzas molasses.	St. Croix molasses.	Trinidad de Cuba molasses.
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 10.	No. 13.	No. 15.	No. 19.	No. 20.	No. 21.
Specific gravity -	1.361	1.348	1.384	1.375	1.369	1.321	1.376	1.371	1.297	1.361	1.362	1.365
Weight of one gallon in avoirdupois pounds	11.34	11.23	11.53	11.48	11.41	11.01	11.47	11.42	10.82	11.34	11.35	11.37
Extractive and other foreign matter -	4.60	4.42	3.33	3.87	2.26	2.12	4.38	3.70	2.14	4.55	3.56	4.12
Crystallizable sugar -	31.45	-	27.13	-	39.27	40.81	24.72	27.94	43.65	-	33.4	32.27
Quality of sugar expressed in numbers from lowest up -	3	-	1	-	6½	7	5½	3½	5	-	3	2

In regard to the first horizontal column, it may be remarked, that in those specimens where sugar had settled at the bottom, it was carefully stirred up with the molasses, before taking portions either for ascertaining the specific gravity, or for determining the amount of crystallizable sugar, &c. The specific gravity of the supernatant molasses would of course be somewhat lower. The second horizontal column is calculated from the first, and gives the true average weight of a gallon of the whole hogshead. Columns 3 and 4 give the comparative amount of extractive and other foreign matter, and of crystallizable sugar, in 100 parts of the molasses. These numbers must not be considered as determined with such scientific accuracy as can be obtained in other experiments, but still to be near enough to the truth to afford a good comparison, for practical purposes, of their content of crystallizable sugar. The last horizontal column expres-

ses the apparent purity of the sugar, as we obtained it in our experiments from the different specimens.

Specimens Nos. 2, 3, 13, and 15, exhibited no appearance of any deposition of sugar in them. In No. 21 there is a slight deposition, and also a small one in Nos. 1, 10, 20, and 19, while the deposition in Nos. 4 and 5 is more considerable, and quite large in No. 6.

The greater or less specific gravity depends on the quantity of uncrystallizable sugar and foreign matter, both of which are more soluble than crystallizable sugar, and therefore increase as the molasses are concentrated. The more of the molasses sugar they possess, the higher is therefore their specific gravity, (column 1;) the greater the amount of foreign matter, (column 3;) and the smaller the amount of crystallizable sugar, (column 4;) and in the same proportion is the latter more difficult to separate, and of inferior quality, (column 5).

We have been informed, from respectable sources, that the manufacture of inferior sugars from West India molasses has been carried on formerly when brown sugar sold at a high price. The amount obtained was from 30 to 35 per cent., but it was only from such molasses as had not been left long enough to deposit all its sugar, or from lack of strength in the sugar, or from carelessness, had carried away with it the finer particles of the sugar. The highest amount obtained was 35 per cent., while some of the New Orleans molasses were said to yield none. Another not unimportant object in this manufacture is the improvement of the molasses by the separation of the sugar and the purification which it undergoes for the purpose, as mentioned above.

We are indebted to Mr. T. Stewart and Dr. D. B. McGinley for the following information in regard to the amount of sugar obtained from molasses, as carried on at the present time in this city. Cienfuegos (Cuba) molasses, weighing 11½ pounds to the gallon, yielded from 400 to 500 pounds of sugar to the hogshead. Supposing the hogshead to contain 125 gallons, this would be from 27 to 34 per cent. A single hogshead of the same cargo should have yielded as much as 600 pounds, or about 41 per cent. Other (Porto Rico) molasses yield 3 to 4 pounds to the gallon, or from 26 to 34 per cent. The better varieties of molasses sugar are worth 6 cents per pound. The molasses lose about one-third by this process.

Respectfully yours,

JAMES C. BOOTH,
MARTIN H. BOYE.

CALVIN BLYTHE, Esq.,

Collector of the Port of Philadelphia.

TABLE I.

Temp. 63½° Fahr.		Temp. 63½° Fahr.		Temp. 63½° Fahr.		Temp. 63½° Fahr.	
Sugar per cent.	Density.	Sugar per cent.	Density.	Sugar per cent.	Density.	Sugar per cent.	Density.
1	1.0035	18	1.0734	35	1.1538	52	1.2434*
2	1.0070	19	1.0784	36	1.1582	53	1.2490
3	1.0106	20	1.0830	37	1.1631	54	1.2546
4	1.0143	21	1.0875	38	1.1681	55	1.2602
5	1.0179	22	1.0920	39	1.1731	56	1.2658
6	1.0215	23	1.0965	40	1.1781	57	1.2714
7	1.0254	24	1.1010	41	1.1832	58	1.2770
8	1.0291	25	1.1056	42	1.1883	59	1.2826
9	1.0328	26	1.1103	43	1.1935	60	1.2882
10	1.0367	27	1.1150	44	1.1989	61	1.2933
11	1.0410	28	1.1197	45	1.2043	62	1.2994
12	1.0456	29	1.1245	46	1.2098	63	1.3050
13	1.0504	30	1.1293	47	1.2153	64	1.3105
14	1.0552	31	1.1340	48	1.2209	65	1.3160
15	1.0600	32	1.1388	49	1.2265	66	1.3215
16	1.0647	33	1.1436	50	1.2322		
17	1.0698	34	1.1484	51	1.2378		

TABLE II.

Sugar per ct. by weight.	Degrees (Baumé) 59° Fahr.	Specific gravity at 59° Fahr.	Sugar, by weight, in kilograms. (Kilo. = 2.205 pounds.)	Water, by weight, in kilograms. (Kilo. = 2.205 pounds.)	Volume in litres. (Lit. = 0.2205 imp. gallons.)	Weight of sugar in 100 litres, or 22.05 gallons.
						Kilog.
3.2	1.75	1.015	100	2945	3000	3.33
3.3	2.	1.018	100	2445	2500	4.
4.8	2.50	1.022	100	1945	2000	5.
6.4	3.50	1.030	100	1445	1500	6.66
9.5	5.	1.045	100	945	1000	10.
11.7	6.50	1.0559	100	750	805	12.42
13.3	7.50	1.0638	100	650	705	14.18
15.3	8.50	1.0744	100	550	605	16.5
18.1	10.15	1.0891	100	450	505	19.8
22.2	12.50	1.1111	100	350	405	24.6
28.5	16.	1.1475	100	250	305	32.7
33.3	18.50	1.1707	100	200	256.25	39.
35.7	19.50	1.1765	100	180	238	42.
38.4	21.	1.1872	100	160	219	45.66
41.6	22.50	1.2000	100	140	200	50.
45.4	25.	1.2222	100	120	180	55.5
50.	27.25	1.2578	100	100	159	62.88
52.6	29.	1.2666	100	90	150	66.66
55.5	30.50	1.2811	100	80	140.5	71.17
58.8	32.	1.2979	100	70	131	76.35
62.5	33.75	1.3223	100	60	121	82.64
66.6	37.	1.3453	100	50	111.5	89.68

TABLE III.

Per cent. of cane sugar in the unit of weight of the solution.	Density of the solution; that of distilled water being unity.	Arc of rotation described by the plane of polarization of the red ray, transmitted through a thickness of 160 millimetres.	Per cent. of cane sugar in the unit of weight of the solution.	Density of the solution; that of distilled water being unity.	Arc of rotation described by the plane of polarization of the red ray, transmitted through a thickness of 160 millimetres.
1	1.004	0.888	10	1.040	9.196
2	1.008	1.783	11	1.045	10.153
3	1.012	2.684	12	1.049	11.128
4	1.016	3.593	13	1.053	12.104
5	1.020	4.509	14	1.057	13.087
6	1.024	5.432	15	1.062	14.079
7	1.028	6.363	25	1.105	24.413
8	1.032	7.300	50	1.231	54.450
9	1.036	8.244	65	1.311	75.394

TABLE IV.

Constructed by M. Francœur, showing the correspondence of the degrees of Beaumé's hydrometers with specific gravities at 54½° Fahrenheit.

Pèse-acide of Beaumé.						Pèse-esprit of Beaumé.			
Deg.	Spec. grav.	Deg.	Spec. grav.	Deg.	Spec. grav.	Deg.	Spec. grav.	Deg.	Spec. grav.
0	1.0000	26	1.2063	52	1.5200	10	1.0000	36	0.8488
1	1.0066	27	1.2160	53	1.5353	11	0.9932	37	0.8439
2	1.0133	28	1.2258	54	1.5510	12	0.9865	38	0.8391
3	1.0201	29	1.2358	55	1.5671	13	0.9799	39	0.8343
4	1.0270	30	1.2459	56	1.5833	14	0.9733	40	0.8295
5	1.0340	31	1.2562	57	1.6000	15	0.9669	41	0.8249
6	1.0411	32	1.2667	58	1.6170	16	0.9605	42	0.8202
7	1.0483	33	1.2773	59	1.6344	17	0.9542	43	0.8156
8	1.0556	34	1.2881	60	1.6522	18	0.9480	44	0.8111
9	1.0630	35	1.2992	61	1.6705	19	0.9420	45	0.8066
10	1.0704	36	1.3103	62	1.6889	20	0.9359	46	0.8022
11	1.0780	37	1.3217	63	1.7070	21	0.9300	47	0.7978
12	1.0857	38	1.3333	64	1.7273	22	0.9241	48	0.7935
13	1.0935	39	1.3451	65	1.7471	23	0.9183	49	0.7892
14	1.1014	40	1.3571	66	1.7674	24	0.9125	50	0.7849
15	1.1095	41	1.3694	67	1.7882	25	0.9068	51	0.7807
16	1.1176	42	1.3818	68	1.8095	26	0.9012	52	0.7766
17	1.1259	43	1.3945	69	1.8313	27	0.8957	53	0.7725
18	1.1343	44	1.4074	70	1.8537	28	0.8902	54	0.7684
19	1.1428	45	1.4206	71	1.8765	29	0.8848	55	0.7643
20	1.1515	46	1.4339	72	1.9000	30	0.8795	56	0.7604
21	1.1603	47	1.4476	73	1.9241	31	0.8742	57	0.7565
22	1.1692	48	1.4615	74	1.9487	32	0.8690	58	0.7526
23	1.1783	49	1.4758	75	1.9740	33	0.8639	59	0.7487
24	1.1875	50	1.4902	76	2.0000	34	0.8588	60	0.7449
25	1.1968	51	1.4951			35	0.8538	61	0.7411

TABLE V,

Showing the discordant results of different observers, obtained by experimental comparison of Beaumé's hydrometers with specific gravities at 54½° Fahrenheit.

Pèse-acide.				Pèse-esprit.				
Deg.	Francœur.	Delezennes.	Gilpin.	Deg.	Francœur.	Delezennes.	Gilpin.	Holland pharma- copœa.
0	1.0000	1.0000	1.000	10	1.0000	1.0000	1.000	1.000
3	1.0201	1.0219	1.020	15	0.9669	0.9655	0.963	0.967
6	1.0411	1.0448	1.040	20	0.9359	0.9333	0.928	0.935
9	1.0630	1.0687	1.064	25	0.9068	0.9033	0.897	0.906
12	1.0857	1.0937	1.089	30	0.8795	0.8751	0.867	0.878
15	1.1095	1.1200	1.114	31	0.8742	0.8696	0.861	0.873
18	1.1343	1.1475	1.140	32	0.8690	0.8643	0.856	0.868
21	1.1603	1.1764	1.170	33	0.8639	0.8590	0.852	0.863
24	1.1875	1.2068	1.200	34	0.8588	0.8539	0.847	0.858
27	1.2160	1.2389	1.230	35	0.8538	0.8486	0.842	0.852
30	1.2459	1.2727	1.261	36	0.8488	0.8435	0.837	0.847
33	1.2773	1.3083	1.295	37	0.8439	0.8384	0.832	0.842
36	1.3103	1.3333	1.333	38	0.8391	0.8334	0.827	0.837
39	1.3451	1.3861	1.373	39	0.8343	0.8285	0.822	0.832
42	1.3818	1.4285	1.414	40	0.8295	0.8236	0.817	0.828
45	1.4206	1.4735	1.455	41	0.8249	0.8188	0.814	0.823
48	1.4615	1.5217	1.500	42	0.8202	0.8141	0.811	0.819
51	1.4951	1.5730	1.547	43	0.8156	0.8094	0.808	0.814
54	1.5510	1.6279	1.594	44	0.8111	0.8017	0.805	0.810
57	1.6000	1.6868	1.659	45	0.8066	0.8001	0.802	0.805
60	1.6522	1.7501	1.717	46	0.8022	0.7956	0.799	0.800
63	1.7070	1.8184	1.779	47	0.7978	0.7911	0.797	0.796
66	1.7674	1.8922	1.848	48	0.7935	0.7866	0.795	0.792
69	1.8313	1.9721	1.920	49	0.7892	0.7823	0.793	0.787
70	1.8537	2.0003		50	0.7849	0.7779	0.791	0.782

TABLE VI.

Per cent. of alco- hol by the alco- holometer.	Gay Lussac's spe- cific gravity at 15° C., accord- ing to Marozeau.	Tralles's specific gravity at 60° Fahr., according to Tralles.	Meissner's specific gravity at 14° R., according to Joss.	Per cent. of alco- hol by the alco- holometer.	Gay Lussac's spe- cific gravity at 15° C., accord- ing to Marozeau.	Tralles's specific gravity at 60° Fahr., according to Tralles.	Meissner's specific gravity at 14° R., according to Joss.
0	1.000	0.9991	1.000	55	0.926	0.9234	0.919
5	0.993	0.9919	0.993	60	0.915	0.9126	0.908
10	0.987	0.9857	0.986	65	0.904	0.9013	0.896
15	0.981	0.9802	0.980	70	0.891	0.8892	0.883
20	0.976	0.9751	0.976	75	0.879	0.8765	0.870
25	0.971	0.9700	0.970	80	0.865	0.8631	0.857
30	0.966	0.9646	0.964	85	0.851	0.8488	0.843
35	0.960	0.9583	0.958	90	0.835	0.8332	0.829
40	0.953	0.9510	0.949	95	0.818	0.8157	0.811
45	0.945	0.9427	0.940	100	0.795	0.7939	0.793
50	0.936	0.9335	0.930				

SECRET

MEMORANDUM FOR THE SECRETARY OF THE TREASURY

Subject: [Illegible]

Reference is made to [Illegible]

Very respectfully,

[Illegible Signature]

[Illegible Title]

March 5, 1942

[Illegible Address]

[Illegible]

[Illegible]

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[Illegible]

TABLE V.

Showing the dependent results of a direct comparison between the experimental comparison of Deane's hygrometer with water at 50° Fahrenheit.

Temperature			Relative			Humidity	
Bar.	Therm.	Wet.	Bar.	Therm.	Wet.	Bar.	Therm.
30	50.00	1.000	30	50.00	1.000	30	50.00
31	50.00	1.000	31	50.00	1.000	31	50.00
32	50.00	1.000	32	50.00	1.000	32	50.00
33	50.00	1.000	33	50.00	1.000	33	50.00
34	50.00	1.000	34	50.00	1.000	34	50.00
35	50.00	1.000	35	50.00	1.000	35	50.00
36	50.00	1.000	36	50.00	1.000	36	50.00
37	50.00	1.000	37	50.00	1.000	37	50.00
38	50.00	1.000	38	50.00	1.000	38	50.00
39	50.00	1.000	39	50.00	1.000	39	50.00
40	50.00	1.000	40	50.00	1.000	40	50.00
41	50.00	1.000	41	50.00	1.000	41	50.00
42	50.00	1.000	42	50.00	1.000	42	50.00
43	50.00	1.000	43	50.00	1.000	43	50.00
44	50.00	1.000	44	50.00	1.000	44	50.00
45	50.00	1.000	45	50.00	1.000	45	50.00
46	50.00	1.000	46	50.00	1.000	46	50.00
47	50.00	1.000	47	50.00	1.000	47	50.00
48	50.00	1.000	48	50.00	1.000	48	50.00
49	50.00	1.000	49	50.00	1.000	49	50.00
50	50.00	1.000	50	50.00	1.000	50	50.00
51	50.00	1.000	51	50.00	1.000	51	50.00
52	50.00	1.000	52	50.00	1.000	52	50.00
53	50.00	1.000	53	50.00	1.000	53	50.00
54	50.00	1.000	54	50.00	1.000	54	50.00
55	50.00	1.000	55	50.00	1.000	55	50.00
56	50.00	1.000	56	50.00	1.000	56	50.00
57	50.00	1.000	57	50.00	1.000	57	50.00
58	50.00	1.000	58	50.00	1.000	58	50.00
59	50.00	1.000	59	50.00	1.000	59	50.00
60	50.00	1.000	60	50.00	1.000	60	50.00

TABLE VI.

Temperature		Relative		Humidity		Temperature	
Bar.	Therm.	Wet.	Bar.	Therm.	Wet.	Bar.	Therm.
30	50.00	1.000	30	50.00	1.000	30	50.00
31	50.00	1.000	31	50.00	1.000	31	50.00
32	50.00	1.000	32	50.00	1.000	32	50.00
33	50.00	1.000	33	50.00	1.000	33	50.00
34	50.00	1.000	34	50.00	1.000	34	50.00
35	50.00	1.000	35	50.00	1.000	35	50.00
36	50.00	1.000	36	50.00	1.000	36	50.00
37	50.00	1.000	37	50.00	1.000	37	50.00
38	50.00	1.000	38	50.00	1.000	38	50.00
39	50.00	1.000	39	50.00	1.000	39	50.00
40	50.00	1.000	40	50.00	1.000	40	50.00
41	50.00	1.000	41	50.00	1.000	41	50.00
42	50.00	1.000	42	50.00	1.000	42	50.00
43	50.00	1.000	43	50.00	1.000	43	50.00
44	50.00	1.000	44	50.00	1.000	44	50.00
45	50.00	1.000	45	50.00	1.000	45	50.00
46	50.00	1.000	46	50.00	1.000	46	50.00
47	50.00	1.000	47	50.00	1.000	47	50.00
48	50.00	1.000	48	50.00	1.000	48	50.00
49	50.00	1.000	49	50.00	1.000	49	50.00
50	50.00	1.000	50	50.00	1.000	50	50.00
51	50.00	1.000	51	50.00	1.000	51	50.00
52	50.00	1.000	52	50.00	1.000	52	50.00
53	50.00	1.000	53	50.00	1.000	53	50.00
54	50.00	1.000	54	50.00	1.000	54	50.00
55	50.00	1.000	55	50.00	1.000	55	50.00
56	50.00	1.000	56	50.00	1.000	56	50.00
57	50.00	1.000	57	50.00	1.000	57	50.00
58	50.00	1.000	58	50.00	1.000	58	50.00
59	50.00	1.000	59	50.00	1.000	59	50.00
60	50.00	1.000	60	50.00	1.000	60	50.00